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October 2, 2017

Written *Ex Parte* Communication

Ms. Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, S.W.
Room TW-A325
Washington, D.C. 20554

Re: ***Use of Spectrum Bands Above 24 GHz for Mobile Radio Services, GN Docket No. 14-177; IB Docket Nos. 15-256, 97-95; WT Docket No. 10-112***

Dear Ms. Dortch:

T-Mobile USA, Inc. ("T-Mobile")[1] submits the attached technical study, which responds to the questions posed in the Commission's *Spectrum Frontiers Report and Order and Further Notice* regarding how best to promote 5G deployment in the bands above 24 GHz while protecting incumbent services, including the passive radio astronomy and passive earth-exploration satellite services adjacent to several of the targeted bands.[2] The study concludes that 5G deployments in the 32 GHz, 47 GHz, and 50 GHz bands can coexist with existing radio astronomy services ("RAS") and the Earth Exploration Satellite Service ("EESS").

The study analyzes the potential for coexistence between 5G wireless broadband operations and passive services located adjacent to the proposed frequencies of 5G operations in the 32 GHz, 47 GHz, and 50 GHz bands. The study relies on widely accepted assumptions regarding the operating parameters of future 5G technologies as well as current RAS and EESS operations. Wherever possible, the study employs ITU recommendations and conservative inputs that tend to overstate the potential likelihood of interference to RAS and EESS operations. Notwithstanding the use of conservative assumptions biased *against* a finding of no harmful interference, the

[1] T-Mobile USA, Inc. is a wholly owned subsidiary of T-Mobile US, Inc., a publicly traded company.

[2] *Use of Spectrum Bands Above 24 GHz for Mobile Radio Services*, Report and Order and Further Notice of Proposed Rulemaking, 31 FCC Rcd 8014 (2016).

analysis demonstrates how coexistence among 5G and RAS and EESS operations in the 32 GHz, 47 GHz, and 50 GHz bands is readily feasible.

In each of the bands studied, the FCC can protect RAS, EESS, and other passive services against harmful interference by adopting modest operating constraints on new 5G broadband services. For example, adopting geographic separation and coordination zone requirements can protect RAS operations with little effect on 5G deployments nationwide because RAS sites are limited in number and mostly located in remote areas. Similarly, technical innovations in 5G systems will substantially limit the aggregate amount of out-of-band emissions EESS will experience even under line-of-sight conditions. These and other factors support the conclusion that 5G operations in the 32 GHz, 47 GHz, and 50 GHz bands can coexist with passive services without risking harmful interference even under worst-case conditions.

This study of 5G coexistence scenarios offers an important foundation for further analysis. Real-world conditions are likely to prove much more favorable to coexistence than the assumptions we employ here. Furthermore, once the final 5G standard is known, new mechanisms for coexistence that have not yet been addressed here may prove worthy of further analysis. Even under the worst-case assumptions and conditions identified in this study, however, traditional sharing techniques, such as coordination, exclusion zones, and possibly certain constraints on 5G operations on some channels and in some geographies, will permit next-generation wireless broadband services in the 32 GHz, 47 GHz, and 50 GHz bands to coexist with adjacent-channel RAS, EESS, and other passive services on adjacent frequencies.

* * *

Should the Commission have questions concerning this filing, please feel free to contact me.

Sincerely,

/s/ Steve Sharkey

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T · · Mobile ·

UNLEASHING MILLIMETER WAVE SPECTRUM
IN THE 32 GHZ, 47 GHZ, AND 50 GHZ BANDS:

COEXISTENCE OF MOBILE BROADBAND OPERATIONS

WITH THE EARTH EXPLORATION SATELLITE SERVICE AND RADIO ASTRONOMY SERVICE

Executive Summary

The Federal Communications Commission ("FCC") has proposed service rules to support next-generation wireless services in numerous bands above 24 GHz. Recent technical developments have made these bands capable of supporting very high speed, very low latency broadband services. But some of these bands are adjacent to passive services that require protection against harmful interference. In its Spectrum Frontiers Further Notice, the FCC posed a series of questions regarding how best to promote 5G deployment in these frequencies while protecting incumbent services, including the passive radio astronomy and passive earth-exploration satellite services.

This report studies the potential for coexistence between 5G wireless broadband operations in the 32 GHz, 47 GHz, and 50 GHz bands and passive services located adjacent to the proposed frequencies of operation. We conclude that 5G deployments in the 32 GHz, 47 GHz, and 50 GHz bands can coexist with existing radio astronomy services ("RAS"), Earth Exploration Satellite Service ("EESS"), and other passive services without causing harmful interference. To reach this conclusion, we relied on widely accepted assumptions regarding the operating parameters of future 5G technologies as well as current RAS and EESS operations. Wherever possible, we employed ITU recommendations and conservative inputs that overstate the potential likelihood of interference to RAS and EESS operations. Notwithstanding our use of very conservative assumptions biased against a finding of no harmful interference, coexistence among 5G and RAS and EESS operations in the 32 GHz, 47 GHz, and 50 GHz bands is readily feasible.

In each of the bands studied, the FCC can protect RAS, EESS, and other passive services against harmful interference from new 5G deployments by adopting modest operating constraints on new 5G broadband services. RAS sites are limited in number and mostly located in remote areas; therefore, adopting a set of geographic separation and coordination zone requirements can protect RAS operations with little effect on 5G deployments nationwide. Similarly, although EESS sensors can scan the entire globe, EESS will experience more path loss than RAS and technical innovations in 5G systems will substantially limit the aggregate amount of out-of-band emissions EESS will experience even under line-of-sight conditions. Specifically, to overcome the poor propagation characteristics of millimeter wave bands, 5G will implement beamforming in both base stations and mobile devices. Beamforming will result in the majority of power directed along the primary communications path and very little in other directions, and therefore it will improve the ability of 5G base stations and mobile devices to protect passive services in adjacent bands. For example, the primary communications path between a base station and a mobile device is almost never vertical, as would be required to direct interference power at an EESS satellite. Thus beamforming helps to create a large amount of antenna discrimination in the direction of potential victim receivers. In addition, mobile devices transmitting in the spectrum immediately adjacent to the passive band will typically use less than the entire 200 (or 500) megahertz-wide channel, which will further reduce the potential for interference into EESS. Taken together, these factors support the conclusion that 5G operations in the 32 GHz, 47 GHz, and 50 GHz bands can coexist with passive services.

32 GHZ BROADBAND DEPLOYMENTS

The FCC proposed allocating the 31.8-33.4 GHz band for next-generation wireless broadband operations. Immediately below these frequencies, however, is a five hundred megahertz wide primary allocation for RAS, EESS, and other passive services, such as space research. Of the three millimeter wave bands under consideration for supporting 5G services, the 32 GHz band may pose the greatest challenge because this band has relatively favorable propagation characteristics compared to the 47 GHz and 50 GHz frequency bands. But even the 32 GHz band can coexist with passive services in adjacent-band spectrum for numerous reasons, including the necessity of using beamforming to overcome the propagation limitations associated with millimeter wave spectrum, as described above. Beamforming and other 5G innovations will permit 32 GHz broadband deployments to coexist with passive services.

47 GHZ BROADBAND DEPLOYMENTS

The FCC proposed allocating the 47.2-50.2 GHz band for 5G services. In its Spectrum Frontiers Further Notice, the FCC asked what additional safeguards might be needed to protect EESS in the 50.2-50.4 GHz band against the risk of potential interference from 5G deployments in the 47.2-50.2 GHz band. As in the 32 GHz band, the 47 GHz band can support 5G without the need for guard bands or other excessively burdensome constraints to protect adjacent channel passive services given practical constraints on how operators will actually have to deploy 5G services in the field. One of the few analytical differences between our study of the 47 GHz and 32 GHz scenarios is the FCC's proposal to use 500 megahertz channels in the 47 GHz band instead of the 200 megahertz channels the agency has proposed to use in the 32 GHz band. Because out-of-band emissions from larger channels attenuate or "roll-off" more slowly than emissions from smaller channels, the larger channels proposed for the 47 GHz band have greater potential to increase the interference risk for adjacent EESS and other passive services compared to those adjacent to 32 GHz; however, the additional propagation losses at the higher 47 GHz frequencies offset the increase in risk associated with larger channels. The results of our 47 GHz analysis are promising enough to allow for the development of protection measures to ensure compatible operations between 5G and passive services without undue constraints on new 5G deployments.

50 GHZ BROADBAND DEPLOYMENTS

The FCC proposed to allocate the 50.4-52.6 GHz band for 5G use. The same types of passive EESS and space research services found in the 32 GHz and 47 GHz band bookend both the lower and upper portions of this 2200 megahertz of spectrum, and the passive band at the lower end is the same band that is adjacent to the upper portion of the 47 GHz band (i.e. 50.2-50.4 GHz). Not surprisingly, the same basic analysis that applied to the 32 GHz and 47 GHz bands applies to the 50 GHz band: the 50 GHz band can support 5G without excessively burdensome constraints on 5G to protect adjacent channel passive services. Among other things, the types of smaller, 200 megahertz channels the FCC has proposed for the 50 GHz band as well as the inferior propagation characteristics of the 50 GHz band relative to lower-frequency spectrum make the 50 GHz especially manageable for 5G deployment. That said, achieving sufficient protection for EESS in the 50.2-50.4 GHz band may require some operational constraints if 5G operations are deployed in both the 47 GHz and 50 GHz bands because the effects of emissions would be cumulative on the interstitial passive services between the two 5G bands. For example, a small guard band could be incorporated at the top of the 47 GHz band allocation or the FCC could reduce the risk of interference by requiring smaller bandwidth channels at the upper end of the 47 GHz band. Protecting passive services in the 52.6-54.25 GHz band should require the least constraints on 5G deployments of any of the three bands under consideration in this report.

Our study of 5G coexistence scenarios offers an important foundation for further analysis. We use conservative assumptions to establish the feasibility of coexistence between next-generation 5G operations and passive services under worst-case conditions. Real-world conditions are likely to prove much more favorable to coexistence than the assumptions we employ here. Furthermore, once the final 5G standard is known and as additional information about the performance criteria of passive systems becomes available, new mechanisms for coexistence that have not yet been addressed here may prove worthy of analysis. But even under worst-case conditions, traditional sharing techniques, such as coordination, exclusion zones, and certain constraints on 5G operations on some channels, will permit the FCC to authorize the deployment of next-generation wireless broadband services in the 32 GHz, 47 GHz, and 50 GHz bands without causing an unacceptable risk of harmful interference to adjacent-channel RAS, EESS operations, and other passive services on adjacent frequencies.

I. Overview

This study examines how commercial mobile broadband operators can use advanced 5G technologies in the 32 GHz, 47 GHz, and 50 GHz bands as proposed by the FCC.[1] We analyze the conditions under which wireless operators can deploy 5G services in these bands while protecting Federal RAS observations and the EESS against harmful interference. Standard operating parameters for 5G systems are not yet definitive and the precise network architecture and use cases for these next-generation wireless systems are not fully defined. Based on a set of conservative assumptions for 5G network operating parameters, however, 5G deployments in the 32 GHz, 47 GHz, and 50 GHz bands can coexist with existing RAS and EESS operations without causing harmful interference.

II. General Assumptions and Methodology

A. RAS PROTECTION

RAS is a passive service that receives radio waves of cosmic origin and allows scientists and researchers to better understand the universe. [2] The 1979 World Administrative Radio Conference (WRC-79) established a RAS spectrum allocation, and the FCC subsequently adopted an allocation in the United States.[3] In adopting additional spectrum for RAS in 2004,[4] the FCC said it sought to "promote future developments in technology and equipment, [and] position scientific services to increase our understanding of physical phenomena."[5]

Services operating in the spectrum allocated for RAS observe and analyze star formation, quasars and pulsars, and the properties of the interstellar medium, while providing a platform for researchers to study the chemical evolution of the universe, the detection of extra-solar planets and many other celestial phenomena.[6] RAS is also expected to continue to contribute to advances in imaging techniques and space science. Today, useful RAS frequencies include virtually the entire radiofrequency spectrum, ranging from 2 MHz to 1000 GHz bands and above.[7]

Despite advances in technology, RAS operations tend to employ antennas with large collecting areas and lengthy integration times—features that can make RAS operations susceptible to interference, especially noise received in the far side lobes of RAS telescopes. Given these characteristics, RAS operations are often located in remote, mountainous areas, such as the Robert C. Byrd Green Bank Telescope in Green Bank, West Virginia or the Arecibo Observatory in Arecibo, Puerto Rico.[8] RAS operations are protected from interference by established national radio quiet zones, but conducting operations in remote locations help RAS facilities avoid ambient noise conditions and potential interference from satellite networks and inter-satellite links. These facilities' mountainous settings also help mitigate atmospheric absorption of incoming signals from space that can degrade the accuracy of radio astronomy data.

The FCC has long employed coordination across a wide range of RAS frequencies to avoid harmful interference between passive RAS operations and active radio communications.[9] The 32 GHz band is no exception. Coordination between RAS and 5G operations is readily feasible in the 32 GHz band through a combination of exclusion zones in the immediate vicinity of the antenna and a larger coordination area circling the exclusion zone for each RAS earth station.

The National Academy of Sciences' Committee on Radio Frequencies ("CORF") agrees. CORF is a chief advocate for U.S. scientists, particularly radio astronomers and remote sensing researchers, who use radio frequencies allocated to RAS and EESS for research. The committee works with the FCC to establish radio-frequency requirements and interference protections.[10] CORF "generally supports the sharing of frequency allocations" and explains "RAS bands can be protected regionally by limiting emissions within a certain radius of a facility."[11] According to CORF, fixed-service operations at 32 GHz can be expected to protect RAS when "coordination between prospective transmitting stations and RAS sites [is] based on factors such as altitude and surrounding terrain."[12]

Based on ITU recommendations and conservative assumptions regarding the types of antennas and length of integration times for RAS operations as well as the average detrimental interference projected for the band,[13] exclusion zones for RAS in the 32 GHz band can be relatively small and coordination would be manageable. Protecting RAS receive sites would not prove overly burdensome to adjacent-channel licensees seeking to deploy 5G service to the public.

1. GENERAL ASSUMPTIONS

In the United States, the 31.8-32.3 GHz passive band is currently allocated to the RAS, EEES, and space research service ("SRS") on a primary basis in both the Federal and non-Federal tables.[14] The FCC proposed authorizing fixed and mobile use in the adjacent 32 GHz band (31.8-33 GHz) in its Spectrum Frontiers Notice.[15] The FCC expanded its inquiry to include the 31.8-33.4 GHz band in its Spectrum Frontiers Further Notice in July 2016 because the ITU identified the 31.8-33.4 GHz band as a potential candidate band for 5G.[16] ITU WRC-15 will conduct sharing and compatibility studies for the 32 GHz band, which may lead to an allocation for mobile service in the band at WRC-19 and potentially allow for a globally harmonized mobile services allocation in the band. As the FCC stated in its Spectrum Frontiers Report and Order, there is a "significant amount of contiguous bandwidth available in the 32 GHz band," and "[g]lobal harmonization … will promote global interconnection, roaming, and interoperability."[17] Commenters in the Spectrum Frontiers proceeding have expressed considerable support for allocating the 32 GHz band for fixed and mobile 5G services.[18]

There are currently no non-Federal licensees in the 32 GHz band.[19] Internationally, the 32 GHz band is allocated for the fixed and radionavigation services.[20]

Of the three large bands considered in this study of the feasibility of coexistence between mobile terrestrial uses and incumbent uses, only the 32 GHz band is adjacent to RAS.[21] If additional RAS activity in the United States at 51.4 GHz or above is identified or initiated, we would apply similar calculations to account for operations in the other frequencies under consideration in this study.

a) Radio Astronomy Threshold Interference Levels

To assess the likelihood of interference-free coexistence between terrestrial mobile operators in the 31.8-33.4 GHz band and adjacent-channel RAS, we used the ITU interference threshold defined in the current in-force ITU recommendation entitled Protection Criteria Used for Radio Astronomical Measurements.[22] This 2003 ITU recommendation encourages administrations to take all practical steps to reduce unwanted emissions falling within protected RAS frequencies.[23] The recommendation also notes that, while sharing between RAS and communications services can be difficult, sharing may be practical with coordination among the parties involved.[24] After reviewing the sensitivity of radio telescopes and other RAS equipment to interference, the ITU report provides a table of threshold levels of interference detrimental to radio astronomy observations.[25] The table identifies the center frequency of RAS observations, the bandwidth of operation, minimum antenna noise temperature and receiver noise temperature to derive system sensitivity and threshold interference levels for a variety of RAS operations.[26] For the 32 GHz band, the ITU defines the threshold level of input power as -192 dBW/500 MHz.[27]

b) Emissions from 5G Operations

Standards development for 5G network and user equipment is not yet complete, but the basic system architecture and radio access network functions are well understood. To identify and model the 5G operating parameters capable of producing harmful interference into RAS operations for this study, we used the emissions mask models described in Section III below. We also employed the following assumptions about RAS and 5G system configurations for purposes of this analysis.

(1) 5G Base Station Emissions

For 5G base stations, we assumed that 25% of air-interface resources are used for overhead control functions.[28] Consistent with the analysis performed by Reed Engineering on behalf of Nextlink Wireless, LLC by Reed Engineering (the “Reed Report”), we assumed these resources are not beamformed.[29] We further assumed that the attenuation of overhead control plane signals in the direction of the RAS receiver is 15 dB while the attenuation of beamformed user plane signals in the direction of the RAS receiver is 40 dB. These assumptions are conservative relative to similar assumptions submitted in the record.[30] The analysis considered three simultaneous transmitting base stations to calculate the required separation distance. Finally, we assumed that the 5G base station bandwidth is 200 megahertz, consistent with the proposed channelization of the 32 GHz band the FCC proposed in its recent Spectrum Frontiers Further Notice.[31]

(2) 5G User Equipment Emissions

For 5G user equipment, we assumed 7 dB of losses in addition to free space path loss. These losses could be caused by clutter, terrain, foliage, antenna discrimination, or other factors. Given that the exclusion distance is tens of kilometers and that mobile devices will generally transmit from 1.5 meters above ground level, limiting losses in excess of free-space path loss to only 7 dB represents a very conservative assumption. We further assumed that the mobile device's antenna gain is 0 dBi, which represents the average gain of all mobiles transmitting in all directions. 5G will support uplink beamforming, which means that mobile devices will have positive antenna gain in the direction of the base station. However, when a large number of mobile devices are randomly distributed around a cell site, most of those devices will not be aligned with the victim RAS antenna. Therefore, the antenna gain in the direction of the RAS antenna will be negative for most mobile devices and positive for a few mobile devices, with the average gain across all mobiles equating to 0 dBi.[32] For purposes of calculating the number of simultaneous mobile transmissions that can be supported at the exclusion distance, we assumed that mobile devices may transmit from as far as 1.2 kilometers from the base station. Given the poor propagation of the millimeter wave bands compared to lower-frequency spectrum, assuming a propagation distance of 1.2 kilometers is also an extremely conservative assumption that overstates the potential risk of interference to RAS. Yet another conservative element to the analysis is that the calculation assumes that all mobile devices are 1.2 kilometers closer to the RAS antenna than the base station would be. However mobiles are likely to be distributed somewhat evenly throughout the coverage area of a cell site such that the majority will be less than 1.2 kilometers closer to the RAS antenna than the base station, and roughly half will be farther from the RAS antenna than the base station.

c) Operating Parameters of Radio Astronomy

For RAS operations, we assumed that a RAS receiver has a bandwidth of 300 megahertz. This size receiver bandwidth is relatively small for RAS operations; larger RAS receiver bandwidths tend to improve RAS readings by maximizing the signal-to-noise ratio from the celestial phenomena that are the subject of observation.[33] As RAS receiver bandwidth decreases, the effect of any out-of-band power the RAS bandwidth receives will be larger for each megahertz of RAS spectrum. Because the total power is converted to a Power Spectral Density (PSD in dBm/MHz) and because the largest contribution of interference power is in the few megahertz just outside the interferer's channel, the PSD is higher when the receiver bandwidth is smaller. For example, a 300 MHz receiver bandwidth would see greater power per megahertz than a 500 MHz receiver bandwidth. Both receivers would receive interference from the channel edge to 300 MHz, but the 500 MHz receiver would see additional interference power from 300 to 500 MHz. However, the additional interference power is extremely small compared to the power from 0 to 300 MHz, so spreading the total power across 500 MHz results in less power per megahertz than spreading slightly less interference power across 300 MHz. Smaller RAS receiver bandwidths, such as the 300 megahertz RAS bandwidth assumed here, should therefore be considered a worst case scenario for assessing RAS susceptibility to interference. For purposes of our analysis, we assumed RAS would receive only in the 31.5-31.8 GHz band (i.e., 300 MHz) even though RAS may receive across the entire 31.3-31.8 GHz band. Our assumption of a narrower-than-feasible RAS receiver bandwidth has the conservative effect of increasing the power spectral density of unwanted emissions relative to RAS bandwidth. As a further measure to employ conservative assumptions and mitigate the potential risk of interference to RAS, we assumed that the RAS antenna's side lobe gain is 0 dBi consistent with ITU recommendation ITU-R RA.769-2.[34]

2. METHODOLOGY

The methodology employed relies on the assumptions identified above and incorporates ITU recommendations or 3GPP standards wherever possible. To project the separation distance and number of mobile devices that could operate in the 32 GHz band alongside RAS operations, we calculated the aggregate interference power from 5G base stations using three inputs: (1) the out-of-band emission ("OOBE") power described in Section III, below; (2) the antenna discrimination values (15 dB non-beamformed overhead control plane signals in the direction of the RAS receiver and 40 dB attenuation of beamformed user plane signals in the direction of the RAS receiver) as described above; and (3) a simulation of three simultaneous transmitting base stations as described above. Then, we calculated the required path loss between the RAS antenna and 5G base stations using the ITU threshold and RAS antenna's side lobe gain. With this number, we determined the required separation distance using the free space path loss model.

For mobile devices, we calculated the total out-of-band emissions power for a single mobile device using the out-of-band emissions power described in Section III below. Next, we calculated the total power at the RAS receiver using the total out-of-band power in the RAS receive band, the RAS side lobe antenna gain, free space path loss assuming that mobile devices can be 1.2 kilometers closer to the RAS antenna than base stations, and the other assumed losses. We then compared the total interference power at the RAS antenna to the ITU protection threshold to determine the number of simultaneous transmitting mobile devices can be supported at the calculated distance.

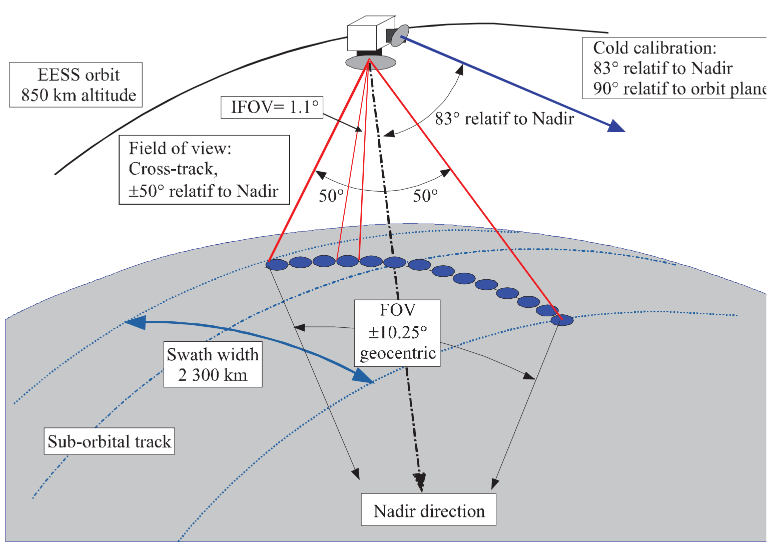
B. EESS/SRS PROTECTION

1. GENERAL ASSUMPTIONS

EESS is a radiocommunication service that includes passive radio sensing with applications in weather forecasting, agriculture, and study of global warming and other global changes of the Earth and its environment.[35] EESS operations use passive sensing, which detects electromagnetic energy generated by natural sources, such as the surface of the Earth and its atmosphere.[36] EESS passive sensors use the amount of energy emitted, transmitted, or reflected to observe and measure objects from a distance in order to determine physical properties of the object, such as temperature, ozone gas concentration, and water vapor profiles.[37] EESS assists with weather prediction and disaster management.[38] As CORF reports, operators in the EESS bands provide "regular and reliable quantitative atmospheric, oceanic, and land measurements to support a wide variety of scientific, commercial, and government (civil and military) data users."[39] Major governmental users include the National Oceanic and Atmospheric Administration, the National Science Foundation, the National Aeronautics and Space Administration, the Department of Defense, especially the U.S. Navy, the Department of Agriculture, the U.S. Geological Survey, the Agency for International Development, the Federal Emergency Management Agency, and the U.S. Forest Service.[40]

The geometry of a typical EESS satellite sensor is shown in Figure 1 below:

In-orbit configuration of a Nadir-sounding passive sensor



Source: Report ITU-R SM.2092, Studies Related to the Impact of Active Services Allocated in Adjacent or Nearby Bands on Earth Exploration-Satellite Service (Passive) (2007)

Figure 1: In-orbit Configuration of a Nadir-Sounding Passive Sensor [41]

As shown in Figure 1, an in-orbit sensor covers a 2,300-kilometer swath of the Earth's surface with multiple pixels, one of which is directly at nadir. Nadir sensors use a sun synchronous polar orbit.[42] For interference purposes, the middle pixel directly at nadir is the worst case because all other pixels will have increased distance from the Earth to the satellite and, thus, additional free space loss. This results in additional attenuation of the interfering signals, and the lower look angles of the off-nadir pixels creates increased opportunities for signals to be blocked by man-made and naturally occurring clutter, especially in urban areas where 5G deployments will be the most dense and aggregate interference to EESS will be highest. Consistent with our intent to evaluate worst-case scenarios, the calculations in this study focus on the center pixel of the EESS sensor pattern, which is nadir to the satellite. The logical corollary is that worst-case interference from terrestrial 5G transmitters will occur in the zenith direction from the 5G transmitter to the satellite.

Notwithstanding the different use cases for EESS, many of the interference considerations resemble those that apply to establishing coexistence between RAS and 5G deployments. Our EESS assumptions are therefore similar to our RAS assumptions, but are adjusted to account for the different frequencies in which EESS receivers operate. Unlike RAS receivers, which are located on Earth, typically in remote, mountainous areas, EESS receivers are located nearly directly overhead transmitting base stations and mobile devices. For this reason, the 5G base station discrimination in the direction of the EESS receiver is greater than in the case of RAS receivers. Beamformed signals are assumed to be attenuated by 40 dB in the zenith direction and non-beamformed signals are assumed to be attenuated by 30 dB. These levels of attenuation are easily achieved with standard antenna patterns.

a) EESS Threshold Interference Levels

The ITU has produced a technical report that provides a methodology and framework for documenting the results of the interference assessment between active, broadband services and EESS passive services operating in adjacent and nearby bands. ITU-R SM.2092,[43] which is an active ITU recommendation that remains in force, references ITU document Recommendation ITU-R RS.1029, entitled "Interference Criteria for Satellite Passive Remote Sensing."[44] However ITU-R RS.1029 has been withdrawn and replaced with ITU-R RS.2017.[45] ITU-R RS.2017 provides information on the performance and interference criteria for satellite passive remote sensing of the Earth and its atmosphere for microwave passive sensors.[46] The required interference protection criteria are more restrictive than those that appear in the withdrawn document, ITU-R RS.1029.[47] In the interest of studying the worst-case interference scenario, we used the more restrictive values in the newer ITU recommendation, ITU-R RS.2017.[48]

For the 31.3-31.8 GHz and 50.2-50.4 GHz EESS bands, the interference protection criterion is -166 dBW/200 MHz. For the 52.6-59.3 GHz EESS band, the interference protection criterion is specified as -169 dBW/100 MHz. When normalized to a power spectral density per megahertz, both criteria equate to -189 dBW per megahertz. EESS satellite criteria are as specified in ITU-R SM.2092.[49] The satellite altitude is 850 kilometers; the pixel size on Earth is 201 square kilometers; and the EESS satellite antenna gain is 45 dBi.[50] The transmit and receive channel bandwidths are the same as for the RAS calculation, and the out-of-band power is also as described in Section III below.

b) Emissions from 5G Operations into EESS

To estimate emissions from 5G operations into EESS, we assumed free space loss from Earth to the EESS satellite. For mobile stations, we assumed 6 dB of loss due to antenna discrimination toward the EESS receiver, which matches a value used by satellite operators to evaluate interference to satellites in geosynchronous orbit.[51] In a later filing, Verizon noted that this assumption of 6 dB "is much too low, given the beamforming to be used for the return link (i.e., from UTs to base stations) and the relative angle to the satellite."[52] Given that the relative angle to the EESS satellite is approximately 90 degrees plus or minus roughly a half degree, this assumption, which was used by satellite operators in an analysis of interference to satellites with relative angles of 15 to 30 degrees, is conservative. Nevertheless, our analysis assumes only 6 dB of antenna discrimination from mobile devices in the zenith direction.[53] Adding to our conservatism, we do not assume any additional attenuation for urban clutter, foliage, or atmospheric absorption. These and other very conservative assumptions will overstate the risk of harmful interference to EESS.

For the purpose of converting the calculated maximum number of sectors that can be supported to the total number of cell sites, we assumed that a 5G system has an average of 2.5 sectors per cell site. Most macro networks include a mix of three-sector sites, two-sector sites, and omni-directional or single-sector sites. In most macro networks, three-sector sites dominate, but the effect of the two-sector and single-sector sites is to reduce the average number of sectors per site in the network. In a small-cell network, many more sites may be single-sector sites. Thus, an assumption of 2.5 sectors per site is conservative and also overstates the potential risk of interference to EESS.[54]

2. METHODOLOGY

The methodology employed for purposes of this coexistence analysis relies on the assumptions identified above and incorporates ITU recommendations and 3GPP standards where possible. To assess the feasibility of coexistence between incumbent systems and proposed 5G base stations, we first calculated the interference power from a single 5G base station sector using two inputs: (1) the OOBE power described below in Section III; and (2) the antenna discrimination values and percentage beamformed traffic assumptions described above. Next, we calculated the interference power from a single sector at the EESS receiver by applying the free space path loss model and accounting for the EESS antenna gain. We then calculated the maximum number of 5G sectors that could be supported within the 201 square kilometer pixel size using the ITU threshold and the total interference power from a single sector. Finally for this portion of the analysis, we calculated the total number of base stations that can simultaneously transmit in a 201 square kilometer area, assuming that the system includes 2.5 sectors per base station.

To assess the coexistence potential of 5G mobile devices with incumbent services, we calculated the total OOBE power for a single mobile device using the OOBE power described in Section III, below. Next, we calculated the total power at the EESS receiver using the total out-of-band power in the EESS receive band, the EESS antenna gain, the antenna discrimination at zenith from mobile devices, and free space path loss from Earth to the satellite. We then compared the total interference power at the EESS antenna to the ITU protection threshold to calculate the number of simultaneous transmitting mobile devices that can be supported in a 201 square kilometer area. The number of mobile devices that can cause interference in a 201 square kilometer area is limited to the number of (outdoor) base station sectors in that area because the technology can typically support only one mobile device transmitting at the edge of the channel at a time using the same resource block.[55] Typically, only one mobile in the same sector can use the same resource block at the same time because LTE uses – and 5G is widely expected to use – orthogonal frequency division multiple access ("OFDMA") technology. The LTE uplink employs a version of OFDMA called Single Carrier Frequency Division Multiple Access ("SC-FDMA") in which multiple mobile devices are scheduled to transmit in a subset of the available resource blocks, with each mobile allocated a contiguous set of resource blocks. By contrast, 3G technologies use code division multiple access ("CDMA") in which all devices use the full bandwidth and are distinguished at the receiver by their unique codes. This coding allows multiple devices to use the same frequency at the same time, which is typically not the case with OFDMA or SC-FDMA.[56] Because 4G and 5G networks employ only one spectrum resource block within any one sector at any one time, the number of mobile devices capable of causing interference generally will not exceed the number of supported sectors in the same area.

In some areas, of course, operators may employ additional means to reduce emissions from base stations in the zenith direction perhaps as a result of better antenna discrimination than assumed here, overhead gain suppression, or other measures. In these cases, the number of supported mobile devices could become the limiting factor with respect to the feasibility of coexistence between incumbent services and new 5G operations. To account for different network configurations and potential changes to the number of supported mobile devices over time, we analyzed the risk of interference from mobile units independently of the risk of the potential interference from base stations.

While both user equipment and base stations require independent analysis, an analysis of aggregate power from base stations and mobile units is not required. The use of Time Division

Duplex ("TDD") operation in the 5G bands will ensure that mobile devices and base stations do not transmit simultaneously. TDD separates in time downstream and upstream directions of traffic.[57] The technique allows a single frequency to be used for both downstream and upstream traffic, and the ratio between downstream and upstream traffic can be fixed or adaptive.[58] Thus, the interference power will either come from a base station or its mobile devices, but not both at the same time. This principle holds true for each sector/cell site, although unsynchronized base stations within the same 201 square kilometer area may result in some OOBE coming from base transmissions and other OOBE from mobile devices. Regardless, the worst case will be when all OOBE are coming from the transmitter with the highest OOBE.

Just as both base stations and user equipment emissions will not be simultaneously visible to an adjacent-channel passive systems, only a portion of the total emissions from mobile devices will be visible to adjacent-channel passive systems. Mobile devices transmitting in spectrum bands that are not directly adjacent to EESS will have a nearly negligible impact on the total OOBE to the EESS receiver. Although Figures 3, 4, and 7 below show the out-of-band emissions leveling off far from the edge of the channel, this apparent outcome is actually a product of the measurement technique and represents the noise floor of the spectrum analyzer. In reality, the power of the OOBE will generally continue to decrease such that the total out-of-band power in the passive band from non-adjacent mobiles will be nearly negligible. For example, assuming the roll-off slope continues at the same rate, a mobile device transmitting in the second adjacent channel would add about 0.2 dB more interference power in the passive band. Since this is well within the margin of error, the interference contribution from the second adjacent carrier is considered negligible.

In addition, the 200-megahertz channel adjacent to EESS may be shared across multiple mobile devices using frequency division, and only one of those mobile devices will be directly adjacent to the 31.8 GHz border with EESS. In a multiple mobile device scenario, moreover, the adjacent mobile device will use less than the entire 200 megahertz-wide channel. For this reason and given constraints on the ability of OFDMA technologies to support more than one end-user device occupying the same spectrum resource blocks at any given point in time, the maximum number of simultaneously transmitting mobile devices that will cause OOBE to the EESS satellite receiver will be equal to the number of sectors in the adjacent-channel spectrum that the EESS receiver can see.

III. Out-of-Band Emissions Model

A. REAL WORLD CONDITIONS

Both international standards-setting bodies and national regulators establish out-of-band emissions masks for device performance. But the out-of-band emission masks that standards-setting bodies and national regulators establish are considerably worse than the actual OOBE performance of devices in the field. 3GPP limits, for example, will often exceed regulatory limits at higher offset frequencies that are farther from the band edge. Similarly, actual device performance will exceed the regulatory and standards-body emissions masks by a considerable margin. Allowing margin or "headroom" to exist between actual device performance and the regulatory-agency or standards-body limit helps ensure devices can meet certification tests and allows for production tolerances sufficiently large to reduce the risk that some lots of devices might exceed the regulatory and/or standard limits due to irregularities in product manufacturing.

The phenomenon of standards bodies and national regulatory bodies employing higher than actual OOBE masks is well understood and widely acknowledged. As the National Institute for Standards and Technology said in October 2016, the assumption that transmitters operate at emissions masks required by standards bodies is "nearly always false."[59] NIST explained that "transmitter out-of-band . . . and spurious emissions are usually substantially lower than emission mask limits, often by tens of decibels."[60] As a result, NIST explained that an analysis that fails to account for higher-than-actual emissions masks will overestimate the power levels of most transmitters' out-of-band emissions, which, in turn, will overestimate the required frequency and distance separations needed for coexistence.[61]

B. DEVELOPING A 5G MODEL

Like other frequencies, the 32 GHz, 47 GHz, and 50 GHz bands will have regulatory limits on out-of-band emissions and spurious emissions. In addition, 3GPP will set limits on out-of-band and spurious emissions for each of the bands when band classes are established through the standards-setting process. Consistent with existing practice, the 3GPP limits can be expected to meet or exceed the regulatory limits.[62] For this reason, using the regulatory limits in an interference calculation is unrealistically conservative. Using 3GPP standard limits instead may offer a slightly more realistic picture of reasonably anticipated field performance, but using 3GPP limits does not account for the additional margin that manufacturers must include in their design to guarantee regulatory and standard compliance of all devices. Of course, the magnitude of the margin available between 3GPP limits and field performance may vary by manufacturer, so assumptions must remain conservative so as to avoid understating the potential risk of interference to RAS and EESS.

To avoid exaggerating interference consequences by relying on standards-body or regulator emissions masks, we relied on the anticipated in-field emissions masks of 5G devices. In our analysis of the 32 GHz and 50 GHz bands, we assumed two hundred megahertz 5G channels consistent with the FCC's proposed band plan.[63] In our analysis of the 47 GHz band, we analyzed both five hundred megahertz channels, which are consistent with the FCC's proposed band plan.[64]

In the Spectrum Frontiers Report and Order, the FCC set OOBE limits for base stations and mobile devices for the 28 GHz, 37 GHz and 39 GHz bands.[65] The FCC set the OOBE limit for both a conductive metric and a total radiated power ("TRP") metric to -13 dBm/MHz, and applied the limit to base stations, transportable stations, and mobile stations.[66] The FCC explained that in the millimeter wave bands, transmitters "require higher gain antennas to compensate for significantly higher propagation losses and consequently the antennas will, in general, have much smaller beamwidth, as compared to other lower band mobile systems."[67] Therefore, "OOBE of mmW [millimeter wave] transmitters have highly directive characteristics, concentrating the transmission power along a narrow beam in the direction of maximum EIRP" and "because the beam is narrow and because a transmitter needs to track the relative movement of its intended receiver in order to maintain the communication link, the OOBE of the mmW transmitter should be spatially averaged over the path of the receiver to reflect the spatially transient nature of the transmitter OOBE."[68] As a result, the FCC decided to express the OOBE limit as an equivalent conductive limit, consistent with the OOBE rule for other mobile systems.[69]

Although the regulatory limits for the three bands examined in this study will be similar to limits that exist today, this similarity is not dispositive because regulatory limits can vary for any number of reasons and an interference analysis based on present-day standards would not be realistic in light of the development of new LTE configurations. Moreover, 3GPP has not yet determined band classes for 5G millimeter wave bands; therefore, no benchmark for the standard emissions masks currently exists that manufacturers might use to ensure compliance.

We can nevertheless reliably estimate key features of 5G operating performance based on observed features of present-day LTE standards, rules and in-field deployment. Due to spectral regrowth, for instance, LTE out-of-band emissions tend to roll off less rapidly with increasing bandwidth. Furthermore, 3GPP OOBE limits for the various channel bandwidths supported by LTE generally scale proportionally.[70] Finally, a direct scaling of 3GPP OOBE limits for small LTE carriers to OOBE limits for larger LTE carriers results in more relaxed OOBE requirements for the larger carriers than 3GPP has specified. These characteristics of LTE performance will not change under a 5G New Radio ("NR") standard. And the persistence of these features into the 5G NR standard allows for a reliable derivation of system performance characteristics of 5G services intended for deployment in the 28 GHz, 37 GHz and 39 GHz bands once differences in bandwidth and other salient features are taken into account.[71]

For mobile devices, in any given LTE frame, a two hundred megahertz channel may be shared across multiple mobile devices using frequency division. The worst-case OOBE power will occur when a single mobile device transmits on the entire two hundred megahertz channel in the uplink. This worst-case scenario will likely be very rare. In most frames of LTE operation, multiple mobile devices communicating with the same sector will share the two hundred megahertz channel, and each of those mobile devices will be allocated only a portion of the available two hundred megahertz of spectrum. In any scenario, only one mobile device will be directly adjacent to the 31.8 GHz border with EESS, and, in a multiple mobile device scenario, the adjacent mobile device will use less than the entire two-hundred megahertz. Frequency division of the two hundred megahertz channel will result in narrower transmissions, which means OOBE will fall off more sharply in a multiple-device scenario than in a worst-case single-device scenario. Because OOBE power is dominated by the power closest to the EESS band, mobile devices transmitting in spectrum that is not directly adjacent to EESS will have a highly attenuated impact on the total OOBE to the EESS receiver. Therefore, the number of transmitting mobile devices simultaneously using the same resource blocks in a 5G OFDMA system that will cause OOBE to the EESS satellite receiver will be equal to the number of sectors that the EESS receiver can tolerate.

To estimate the future 3GPP standard limits for two- and five-hundred megahertz 5G channels, we have assumed that OOBE requirements would scale proportionally to those for a twenty-megahertz LTE carrier. Based on current 3GPP precedent for LTE, this assumption should result in a more permissive emissions mask than will actually be imposed by 3GPP. As a result, an analysis based on a scaled 3GPP mask would assume more power into the adjacent passive band than 3GPP will eventually allow, which means that an analysis would overstate the likelihood of interference into adjacent-band operations. We avoided this outcome by using the scaled and adjusted performance of actual equipment in the OOBE model. But to ensure that our model based on actual performance would meet scaled 3GPP limits, we used Table 6.6.2.1.1-1 of 3GPP 36.101 to determine the proper scaling for mobile devices at larger operating bandwidths.[72]

Table 6.6.2.1.1-1: General E-UTRA spectrum emission mask

Spectrum emission limit (dBm)/ Channel bandwidth							
Δf_{OOB} (MHz)	1.4 MHz	3.0 MHz	5 MHz	10 MHz	15 MHz	20 MHz	Measurement bandwidth
± 0-1	-10	-13	-15	-18	-20	-21	30 kHz
± 1-2.5	-10	-10	-10	-10	-10	-10	1 MHz
± 2.5-2.8	-25	-10	-10	-10	-10	-10	1 MHz
± 2.8-5		-10	-10	-10	-10	-10	1 MHz
± 5-6		-25	-13	-13	-13	-13	1 MHz
± 6-10			-25	-13	-13	-13	1 MHz
± 10-15				-25	-13	-13	1 MHz
± 15-20					-25	-13	1 MHz
± 20-25						-25	1 MHz

Source: 3GPP, Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) Radio Transmission and Reception: Specification # 36.101 (LTE).

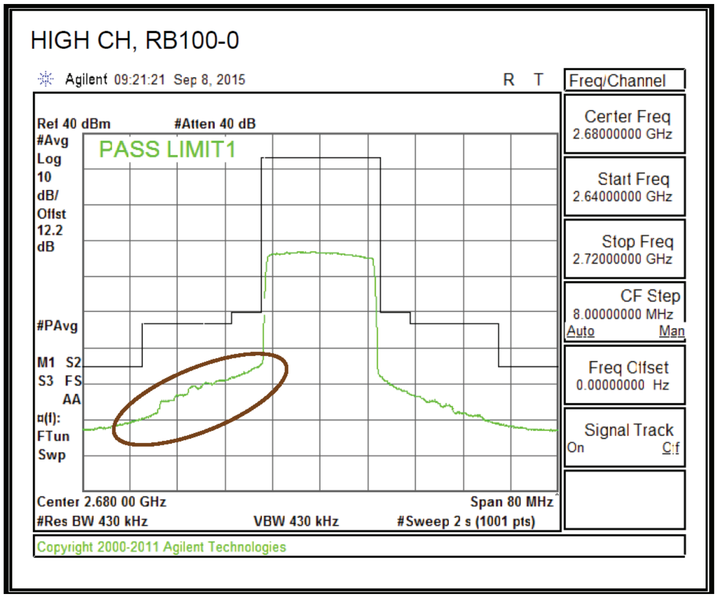
Figure 2: 3GPP Device Emission Masks for LTE

To arrive at the spectrum emissions mask for a 5G device with a two hundred megahertz channel, we multiplied the ΔfOOB ranges above by ten and used the OOBE limit for a twenty-megahertz channel. For example, the maximum OOBE for a twenty-megahertz channel from 0 to 1 MHz outside the occupied bandwidth is -21 dBm per 30 kHz as shown in the table above. For a two hundred megahertz channel, therefore, the maximum OOBE from 0 to 10 MHz outside the occupied bandwidth would be -21 dBm per 30 kHz.

But this straight-line scaling of channel bandwidth does not account for the additional margin attributable to production tolerances and other features discussed above. Therefore, we used OOBE for mobile devices based on actual equipment performance, again scaled to a two hundred megahertz bandwidth. In this case, we conservatively approximated the performance of an iPhone transmitting a 20 MHz LTE channel in Band 41.

OOBE performance of the iPhone varied based on where the channel was located in the band, the side of the channel, and whether the transmission used QPSK or 16QAM modulation. Despite these variations, we were able to approximate the worst-case performance using this method. We found that the lower sider of the uppermost channel when QPSK was the modulation represented the worst-case scenario.[73] In the spectrum-analyzer plot reproduced below, worst-case performance is circled in red. Of course, this plot represents only the beginning of the analysis because tolerances for adjacent channel passive services are not directly related to the OOBE roll-off of a single device. In other words, while emissions for a single device may fall below the mask, assessing interference potential to the passive services requires an analysis of the aggregate power from multiple devices.

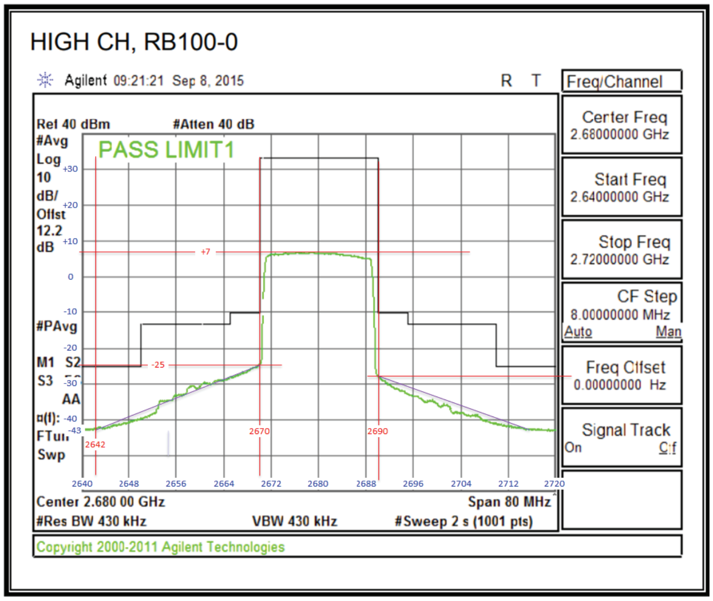
In assessing aggregate interference, there are numerous assumptions and parameters involved, such as distance, receive bandwidth, and other factors. We explain and document our aggregate interference in Sections IV.B.2, V.B.2, and VI.B.2 below.



Source: Agilent Technologies; UL Verification Services Inc., Certification Test Report No. 15U21635-E9V3, FCC ID: BCG-E3042A, for Cellular Phone with Bluetooth and WLAN Radios, at 520 (Feb. 4, 2016).

Figure 3: Worst Case iPhone OOBE Performance

After selecting a worst-case iPhone emissions mask, we then scaled the emissions mask of an iPhone operating on a 20 megahertz LTE channel to a presumptive 5G channel that would use a 200 MHz channel. To accurately scale the iPhone emission mask, we used the radiofrequency operating parameters of the least favorable iPhone emissions mask using QPSK modulation. We then plotted straight lines against the curve of this worst-case iPhone's emissions mask, as shown by the red lines in the graphic below. Representing a curve with straight lines obviously entails some degree of generalization, but we applied conservative measures to our generalization that tend to overstate the OOBE of the iPhone emissions mask. Namely, whenever we generalized a line or angle of the emissions mask curve, we took care to use the line that captured the majority of the emissions within that segment. As a result, any generalizations in this plot of the iPhone's emissions mask will tend to overstate the iPhone's OOBE.



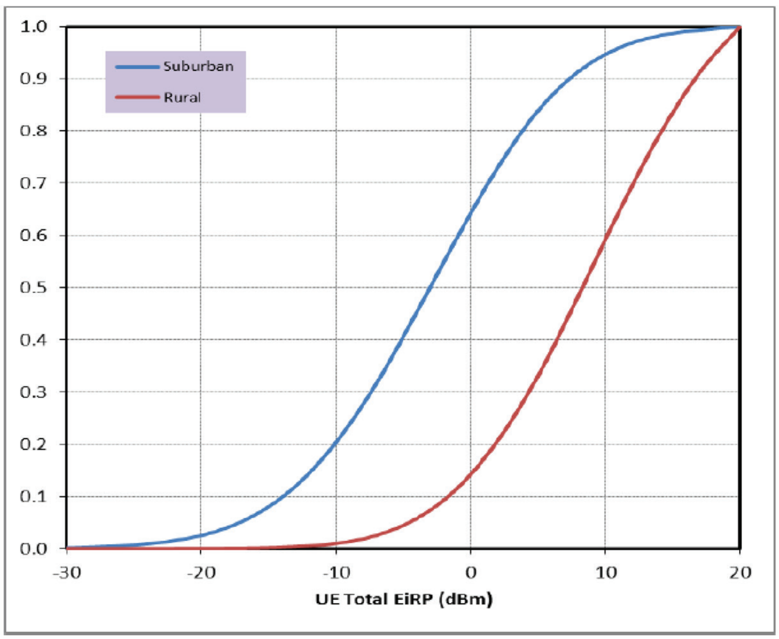
Source: Agilent Technologies, Agilent Technologies; UL Verification Services Inc., Certification Test Report No. 15U21635-E9V3, FCC ID: BCG-E3042A, for Cellular Phone with Bluetooth and WLAN Radios, at 520 (Feb. 4, 2016).

Figure 4: Approximation of Worst Case iPhone OOBE Performance

By carefully measuring each aspect of the iPhone's emissions mask, we developed a precise model of the mask that was capable of replication. We then scaled that performance to a 200 MHz transmit bandwidth using the same method described above.[74] Once the iPhone's performance was plotted and scaled, this performance level was further adjusted as described below to account for average power, performance variation, and production tolerances.

The scaled OOBE described above represents the maximum amount of out-of-band power that a mobile device will generate when operating at full power in a two hundred megahertz channel. In reality, user equipment rarely operates at full power, especially in urban and suburban areas where cell site density is high and the probability of a user being close to a cell site is high. Likewise, most mobile devices will transmit in less than the full 200 MHz bandwidth most of the time, and therefore the roll-off of their out-of-band emissions will be steeper. Due to these conservative assumptions, the full power iPhone operating parameters shown here are conservative and overstate the potential interference risks to RAS and EESS operations.

Consensus-driven studies support the view that actual performance will exceed standards specifications and provide reliable information about just how much lower actual equipment operating power will be in the field. The Commerce Spectrum Management Advisory Committee ("CSMAC"), for example, conducted a study that analyzes mobile device operations in urban and rural environments, which confirms that user equipment operates about 23 dB lower than full power.[75] CSMAC advises the Assistant Secretary for Communications and Information at NTIA on a broad range of spectrum policy issues. CMSAC members are selected based on their technical background and expertise, and provide perspective on reforms to enable new technologies and services.[76] CSMAC Working Group 1 was tasked with developing recommendations for use of the 1695-1710 MHz band for commercial services while protecting Federal meteorological earth stations from harmful interference.[77] In January, 2013, CSMAC Working Group 1 published Monte Carlo simulation results that show that the average transmit power of an LTE mobile device in urban and suburban areas is about 23 dB lower than full power.[78]



Source: CSMAC Final Report, Working Group 1 – 1695-1710 MHz Meteorological-Satellite, at Appendix 3 (Jan. 22, 2013).

Figure 5: CSMAC Report UE EIRP Distributions for Urban/Suburban and Rural

	Urban/Suburban (1.732 Km ISD) (6 UE scheduled/TTI/sector)		Rural (7 Km ISD) (6 UE scheduled/TTI/sector)	
UE EiRP (dBm)	PDF	CDF	PDF	CDF
-40	0.0000	0.0000	0.0000	0.0000
-37	0.0001	0.0001	0.0000	0.0000
-34	0.0002	0.0003	0.0000	0.0000
-31	0.0008	0.0011	0.0000	0.0000
-28	0.0020	0.0031	0.0000	0.0000
-25	0.0040	0.0071	0.0000	0.0000
-22	0.0083	0.0154	0.0002	0.0002
-19	0.0166	0.0320	0.0004	0.0006
-16	0.0327	0.0647	0.0007	0.0013
-13	0.0547	0.1194	0.0026	0.0039
-10	0.0839	0.2033	0.0060	0.0099
-7	0.1128	0.3160	0.0153	0.0252
-4	0.1370	0.4530	0.0325	0.0577
-1	0.1429	0.5959	0.0575	0.1152
2	0.1338	0.7297	0.0911	0.2062
5	0.1094	0.8390	0.1245	0.3307
8	0.0753	0.9143	0.1536	0.4843
11	0.0450	0.9594	0.1605	0.6448
14	0.0236	0.9830	0.1473	0.7920
17	0.0106	0.9936	0.1203	0.9123
20	0.0064	1.0000	0.0877	1.0000

Source: CSMAC Final Report, Working Group 1 – 1695-1710 MHz Meteorological-Satellite, at Appendix 3 (Jan. 22, 2013).

Figure 6: CSMAC Report Tabular UE EIRP Data

The CSMAC data shows that mobile devices operate at approximately -3 dBm half the time, which is 23 dB less than the maximum power used in the simulations.[79] Out-of-band power will scale with the fundamental power.[80] Thus, realistic OOBE based on average power of mobile devices will be 23 dB lower than the OOBE at full power shown in Figures 3 and 4. This power reduction is critical to the EESS analysis because the highest interference power seen by EESS satellites will be where 5G cell site deployments are most dense; and the most dense deployments will be in urban centers.

For the 32 GHz RAS analysis, using the average mobile power in an urban/suburban environment does not offer a realistic portrayal of typical field conditions because most RAS locations are located in remote, rural areas. Therefore, we relied upon the rural power data provided by CSMAC that shows that a mobile's average power in rural areas is approximately 8 dBm, or 12 dB lower than the maximum power permitted by rule.

Although the CSMAC mobile power curves were based on 4G devices and ours is a 5G analysis, the CSMAC results are conservative for our purposes. For example, Ericsson produced a similar power curve for 5G devices, which shows that 5G mobiles will typically operate at a power level that is 31 dB lower than their maximum power.[81] The power level Ericsson employed is 8 dB less mobile power than we have assumed in this analysis and represents yet another element of conservatism. In addition, the CSMAC data was based on the capabilities of 4G devices, which typically operate at 23 dBm EIRP, while 5G devices are expected to operate at 43 dBm. Although on the surface this discrepancy may seem to indicate that 4G OOBE is not a good proxy for 5G OOBE, the two figures actually correspond quite closely because the conducted power of 5G devices will not be significantly different than that of 4G devices. The difference is that radiated power in 4G is omni-directional while radiated power in 5G will use uplink beamforming to give mobile devices a gain of roughly 17 dB in the direction of the base station.[82] Thus, the fundamental conducted power will be very similar, and due to spatial averaging of OOBE from 5G mobiles,[83] the OOBE of a 4G device is reasonably equivalent to the average expected OOBE of a 5G device. For interference calculations to EESS satellites, moreover, the spatial averaging of 5G OOBE in the horizontal plane is nearly irrelevant because only emissions in the zenith direction can cause interference. Furthermore, due to the relatively low height of terrestrial macro base stations and the even lower height of small cells, the vast majority of 5G beamformed uplink transmissions will be at very low elevation angles, very far from the 90 degree angle required to cause interference to EESS. Again, assuming only 6 dB of gain reduction from 5G mobiles in the zenith direction represents a remarkably conservative assumption.

Although we base our mobile OOBE assumptions on the tested performance of an iPhone, our analysis does not assume that all devices will perform as well as the iPhone. After all, the iPhone's OOBE performance may not be representative of the OOBE of all mobile devices transmitting in a given area because some devices may produce more out-of-band emissions power than the iPhone. In addition, OOBE performance could vary even among the same model of device due to production tolerances. To account for these potential variations from the OOBE performance of any given iPhone, we added 5 dB more power to the iPhone OOBE curves. The introduction of additional power into the OOBE plots creates a curve that is higher than the iPhone curve, but still a few dB below the expected 3GPP emissions mask, so that the resulting maximum power performance curve meets the 3GPP requirements by a smaller margin than the iPhone. Using the iPhone as a base case and then plotting an OOBE performance measure 5 dB worse than the iPhone is thus a conservative assumption that nonetheless comports with the expected 3GPP standard requirement and realistically provides margin to ensure that the standard will be met. In addition, our analysis assumes all devices in a given area will perform 5 dB worse than the iPhone. In other words, we not only assume all non-iPhone devices perform 5 dB worse than the iPhone, but also assume that all devices (including the iPhone) always perform at this worse level. The collective effect of these assumptions is to overstate the emissions of user equipment and, thus, exaggerate the potential for interference to passive services.

The OOBE power curves used in our analysis are shown in Figure 7 below. The dashed brown line shows the worst-case, scaled iPhone performance shown in the circled region of Figure 3 above. This represents the iPhone's OOBE at full power, and the difference between the yellow line representing the 3GPP mask and the brown dashed line represents the margin by which the iPhone met the 3GPP standard. The orange line represents a performance level at full power that is

5 dB worse than the iPhone, which reduces the margin by about half. The blue line represents the average power in rural areas per the CSMAC data and is 12 dB lower than the orange line. This blue line represents the OOBE power curve used in the RAS analysis. Finally, the green line represents the average device power in urban and suburban areas per the CSMAC data and is 23 dB lower than the orange line. This green line represents the OOBE power curve used in the EESS analysis.

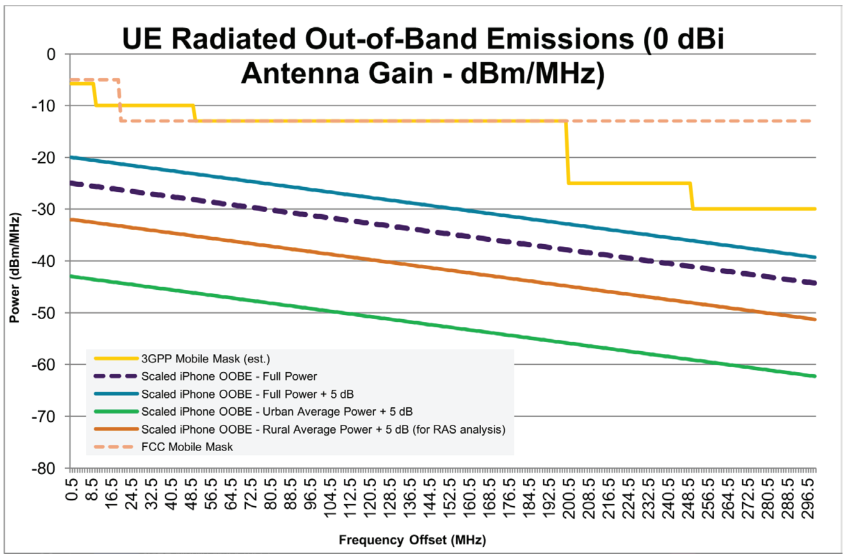
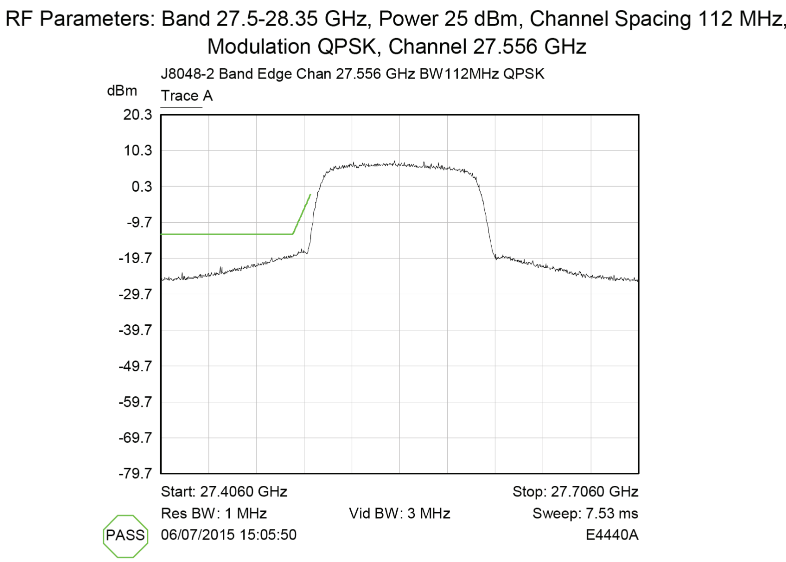


Figure 7: UE Radiated OOBE Power Curves for RAS and EESS Analysis

For base stations, we used a more realistic roll off that outperforms the regulatory and 3GPP limits by a modest 5 dB in most frequency ranges. We also analyzed out-of-band emissions for existing equipment in the band and found that typical roll-off is to -25 dBm per megahertz across roughly the channel bandwidth. Because both standard and regulatory base station emissions masks are generally flat (i.e., the mask remains at the same emissions level as the frequency offset from the edge of the channel increases), reviewing actual equipment performance provides important information about the real-world consequences of 5G base-station operations on adjacent-channel services.

A typical example of actual base station emissions performance with current-generation millimeter wave equipment is shown in Figure 8[84] below:



Source: Cambridge Communication - 2016 29 GHz Test Report

Figure 8: Base Station OOBE Roll-off of Typical 28 GHz Equipment

Equipment currently operating in the millimeter wave spectrum is typically point-to-point or point-to-multipoint equipment; however, 5G base stations are expected to achieve similar, if not better, OOBE performance than current-generation fixed wireless equipment.

But even assuming 5G OOBE performance in the millimeter wave bands is no better than current-generation equipment performance at these frequencies, we would grossly overstate out-of-band power if we were to assume that emissions remain flat as the frequency offset from the edge of the band increases. As shown above, actual emissions generally decrease (i.e., "roll off") as the frequency offset increases. In addition, it is generally easier to filter emissions from base stations than mobile devices because base stations have less restrictive constraints on size and power. Of course, base stations transmit at higher power levels, which serves to offset the enhanced filtering capability of base stations relative to the filtering capability of user equipment. But this offset is of no consequence because base stations can easily meet the roll-off assumptions contained in this analysis and likely can far exceed our roll-off assumptions by incorporating additional filtering into the base stations. Options to reduce OOBE through increased filtering exist today and could be used to ensure services in adjacent bands are protected.

The assumed base station roll-off for a two hundred megahertz transmission is shown in Figure 9 below, along with the FCC requirement, the 3GPP requirement for a twenty megahertz LTE channel scaled to a two hundred megahertz channel bandwidth,[85] and actual performance of existing 28 GHz equipment also scaled to a two hundred megahertz channel bandwidth. This chart clearly shows that scaling the 3GPP requirement to two hundred megahertz results in a requirement that is much more lenient than the FCC's regulatory requirement in the first one hundred megahertz outside the channel. The graph also shows that typical existing mmWave equipment meets the FCC requirement with about 5 to 12 dB of margin. Therefore, for the purpose of assessing interference from 5G base stations to RAS and EESS, we assumed a level of out-of-band emissions performance that just meets the FCC requirement and is similar to but not as aggressive as the roll-off of typical existing equipment. From 0 to 50 MHz, we assumed the roll-off for a two hundred megahertz transmission maintains a slope that is parallel to, and 14 dB below, the 3GPP mask. As shown in Figure 9 below, the assumed performance is required to meet the FCC mask at 10% of the channel bandwidth, which is shown by the red dotted line. Beyond 50 MHz and extending to 200 MHz, the slope of the OOBE roll-off becomes more gentle and roughly parallel to the typical existing equipment performance such that the OOBE at 200 MHz outside the edge of the channel and beyond is -25 dBm per megahertz. This OOBE level is more conservative than the typical existing equipment roll-off shown above and represented by the orange line in Figure 9, because emissions from typical equipment are much lower in the first 10% of the channel bandwidth just outside the band. Due to the relative power levels, the higher power levels just outside the band contribute the most power to the OOBE, and therefore the analyses that follow are much more sensitive to the power levels in the region closest to the fundamental emission than to the power levels two hundred megahertz outside the band.

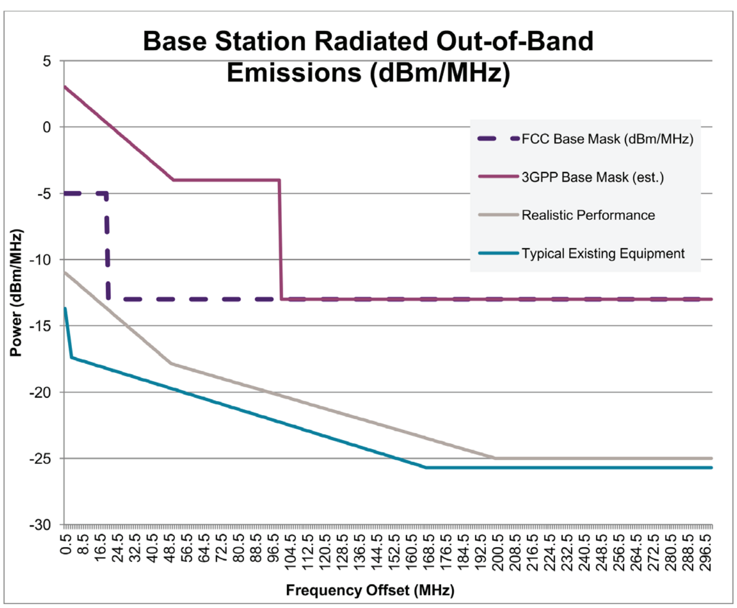


Figure 9: Base Station OOBE Power Roll-off Curves

IV. 32 GHz Band (31.8 – 33.4 GHz)

A. BACKGROUND, BAND PLAN, AND FURTHER NOTICE QUESTIONS

To support the deployment of 5G services in the United States, the FCC has proposed to divide the 31.8-33.4 GHz band into eight, two hundred megahertz channels.[86] As shown below, the lowermost of these new 5G channels is located immediately adjacent to a five hundred megahertz wide primary allocation for RAS and EESS and other passive services that run from 31.3 GHz to 31.8 GHz. In this portion of the band, which is shown in yellow in the diagram, RAS shares a co-primary allocation with EESS and SRS.[87]

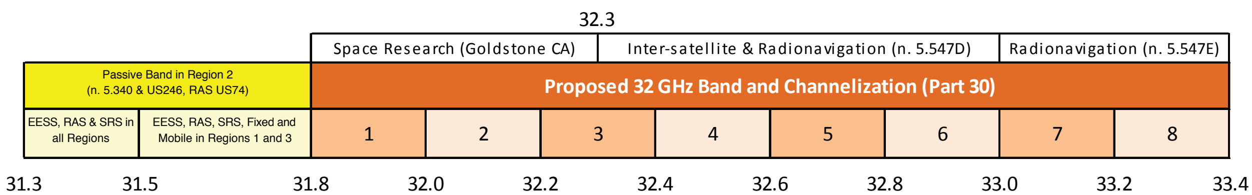


Figure 10: 32 GHz Band Plan

Outside of the passive band, the proposed 32 GHz band 5G allocation overlaps SRS, ISS, and radionavigation services. In the 31.8-32.3 GHz band, there is a Federal allocation to the radionavigation service and SRS (deep space) (space-to-Earth) on a co-primary basis, and a non-Federal allocation to SRS. Federal and non-Federal SRS operations have the same limitations: use of the band for SRS is limited to Goldstone, CA.[88] Administrations must take all necessary measures to prevent harmful interference between the radionavigation service, SRS, and ISS in the band.[89] And all airborne or space station operators are urged to take all practicable steps to protect RAS observations in the adjacent bands from harmful interference.[90]

Between 32.3 GHz and 33 GHz an allocation is available for Federal and non-Federal ISS uses as well as use by the radionavigation service on a co-primary basis. Operators in this band are also required to take all practicable steps to protect RAS observations in the adjacent bands from harmful interference.[91] Operations in this band may include non-geostationary inter-satellite links, which are permitted on a secondary basis to geostationary inter-satellite links.[92] Ground-based radionavigation aids are not permitted in the 31.8-33.4 GHz portion of the band, except where they operate in cooperation with airborne or shipborne radionavigation devices.[93]

Finally, in the 33 GHz to 33.4 GHz band, the radionavigation service has a primary allocation for both Federal and non-Federal services. Ground-based radionavigation aids are not permitted in the 31.8-33.4 GHz portion of the band, except where they operate in cooperation with airborne or shipborne radionavigation devices.[94] Additionally, the band 33-36 GHz is allocated to the FSS (space-to-Earth) on a primary basis for Federal use.[95] Coordination between Federal FSS and non-Federal systems is required.[96] Federal FSS and mobile-satellite services ("MSS") are limited to military systems.[97]

In its Spectrum Frontiers Further Notice, the FCC has asked whether a guard band should be adopted to protect RAS operations in the 31.8 GHz band.[98] The FCC noted concerns raised by CORF that incumbent users in the band designed and developed EESS missions without the expectation of transmissions in close proximity to the 31.3-31.8 GHz band. CORF encouraged the FCC to adopt adequate guard bands to protect EESS operations until current satellites can be replaced with satellites equipped with filtering technologies that are better suited to the FCC's proposed spectrum allocations and emerging applications in those bands. However, operations in the 31.3-31.8 GHz band can be protected without adopting guard bands. Instead, as discussed below, carefully tailored operating requirements can address transmissions from operations in the adjacent band.[99] RAS sites are limited in number and located in remote areas, so geographic separation and coordination zones can provide adequate protection. Furthermore, application of guard bands generally throughout the band would limit wireless systems capabilities unnecessarily given that RAS are only in specified remote locations. EESS and SRS operations in the band can also be protected by establishing some targeted constraints on 5G deployments.[100]

B. PROTECTION OF RAS

1. CALCULATIONS

Detailed calculations are shown in the Appendix, but in general we used the base station emissions model described above to calculate the total out-of-band radiated power that would be seen by a 300 megahertz RAS receiver in the adjacent band. We then calculated the aggregate amount of interference power that would be generated by three simultaneously transmitting base station sectors in the direction of a RAS receiver taking into account the antenna discrimination values for beamformed and non-beamformed transmissions as well as the ratio of this traffic. Using this aggregate interference power, the ITU protection criteria of –192 dBW/500 MHz, and the RAS antenna gain, we calculated the path loss that would be required between the RAS receiver and the interference sources to ensure the ITU protection criteria was not exceeded. We then used the Friis formula to calculate the separation distance required to achieve the required free space path loss, using the center frequency of the passive band in the formula.

The calculation for mobile devices is similar. We used the device emissions model used above to calculate the total out-of-band radiated power that would be seen by a 300 megahertz RAS receiver from a single mobile device. And while we assume 17 dBi of beamforming gain in the direction of the base station, we assume a uniform distribution of mobiles such that the aggregate gain in any direction is 0 dBi. Thus, we assume that there is no antenna discrimination in the direction of the

RAS antenna in the mobile calculation. We then used the distance calculated in the base station calculation and assumed that mobile devices may transmit from 1.2 kilometers closer to the RAS antenna to calculate the path loss required between mobile devices and the RAS antenna to ensure the ITU protection criteria would not be exceeded. As described previously, the 1.2 kilometer distance is a conservative assumption since 5G cell sizes are generally not expected to be so large given the propagation of millimeter wave bands. We then used the out-of-band power from a single mobile device, the required path loss, the RAS antenna gain, and 7 dB of loss to account for losses in the direction of the RAS antenna due to terrain, clutter, and/or foliage, to calculate the interference power from a single device at the RAS receiver. Finally we compared this interference power from a single device to the ITU protection criteria to calculate the maximum number of mobile devices that could transmit simultaneously without exceeding the ITU criteria.

2. RESULTS

The results of the RAS protection calculations are shown in Table 1 below:

	RAS Base		RAS UE	
	Value	Units	Value	Units
OOBE Power in the RAS receive band	5.46	dBm/300 MHz	-13.74	dBm/300 MHz
Total Interference power from one transmitter in the direction of the RAS receiver	-15.52	dBm/300 MHz	-13.74	dBm/300 MHz
Aggregate interference power from three sectors	-10.74	dBm/300 MHz		
Total required path loss	153.47	dB		
Free space path loss distance	35.5	kilometers		
Interference power from a single UE at the RAS receiver			-173.91	dBm/300 MHz
Number of simultaneous transmitting UEs at cell edge			9	

Table 1: Results of RAS Protection Calculations at 32 GHz

These results demonstrate that even with conservative assumptions, including the use of free space loss propagation with no attenuation due to terrain or clutter, exclusion distances required to meet the ITU protection threshold are not exceptionally great and, especially in light of the conservative nature of the assumptions underlying this analysis, appear to provide a solid foundation for coexistence between 5G deployment and radio astronomy services.

C. PROTECTION OF EESS

1. CALCULATIONS

As described earlier, EESS satellites monitor frequencies in the passive bands and pass directly over the surface of the earth at an altitude of 850 kilometers. At any given time, the EESS satellites receive measurements from a circular area with an eight kilometer radius, or 201 square kilometers.[101] Because only one transmitting mobile device will typically occupy a discrete spectrum resource block at any given time in an 5G OFDMA system, interference to EESS satellites from 5G base stations and mobile devices on any particular frequency will be limited to those base stations and devices transmitting in any given 201 square kilometer circular area. Therefore, the analysis generally calculates the number of base stations and mobile devices that can operate in a 201 square kilometer area without exceeding the ITU protection threshold for EESS.

Although base stations just outside the 201 square kilometer circular area could also contribute interference to EESS, the 45 dBi used in our calculations is the peak gain of the EESS antenna,[102] and this peak gain is only achievable near the center of the circular area. The gain of interfering signals from most base stations and mobiles within the 201 square kilometer area will be less than the peak, with those near the edge seeing 3 dB less gain (i.e., half as much interference power). Despite this important mitigating factor, our analysis assumes that interfering signals from all base stations and mobile devices within the area are increased by 45 dB due to the satellite's antenna gain. Therefore, limiting the area of interfering signals to a circle with an eight kilometer radius is statistically accurate.

In addition, EESS space stations circle the Earth once every 102 minutes,[103] which means that their ground speed is approximately 6.5 kilometers per second. As a result, the satellite's eight kilometer radius beam will only stay over any point on Earth (e.g., a base station or mobile) for a maximum of 2.5 seconds, and during this time the base station or mobile may or may not be transmitting. In other words, there is a temporally limited window of opportunity for interference to occur, for which this study has not taken into account in assessing the feasibility of coexistence.

For base stations, we first use the emission model described previously to calculate the total out-of-band power in an adjacent 300 MHz receiver bandwidth. We then use the antenna discrimination assumptions for beamformed and non-beamformed transmissions and the relative percentage of these transmissions to calculate the out-of-band power at the output of the antenna from a single base station sector in the zenith direction toward the EESS satellite. We then calculate the interference power from a single sector at the EESS receiver by applying the free space path loss between the Earth and the EESS satellite and the EESS satellite's antenna gain. This power is then used along with the ITU protection threshold to calculate the total number of sectors from which interference power could be aggregated such that the ITU EESS protection threshold would not be exceeded. As discussed in Section II.B.2 above, we assume a macrocell deployment in which each macro base station includes an average of 2.5 sectors, and this value is used to calculate the number of base stations from the number of sectors. Our base station sector assumptions represent another worst-case estimate because most millimeter wave deployments are expected to be micro cells which will have lower power, lower height, and fewer sectors than a typical macro cell. Therefore, 100 macro cells is equivalent to many more micro cells, and more importantly the aggregate interference power from the equivalent number of micro cells will be lower. Finally, we calculate the implied cell radius using the 201 square kilometer area and the formula for the area of a hexagon.

For mobile devices, the calculation is similar. The total out-of-band power in a 300 MHz receiver bandwidth is calculated using the average device out-of-band power in an urban setting as described above. As with the RAS calculation, we assume no antenna discrimination between the mobile device and the EESS satellite, but we assume a modest 5 dB of losses over free space loss to account for foliage, clutter, and other attenuating effects such as atmospheric absorption. We then add the gain of the EESS antenna to calculate the interference power of a single mobile device at the EESS receiver. Using this value and the ITU protection criteria we then calculate the number of mobile devices that can simultaneously transmit without exceeding the ITU threshold. Since only one mobile device per sector can transmit in the adjacent channel at any given time, the result will be limited by the number of base station sectors if the number of mobiles calculated exceeds the number of sectors that can be supported in a 201 square kilometer area. Otherwise, the number of sectors will be limited to the number of mobiles calculated.

2. RESULTS

The results of the EESS protection calculations are shown in Table 2 below:

	EESS Base		EESS UE	
	Value	Units	Value	Units
OOBE Power in EESS Receiver Bandwidth	5.46	dBm/300 MHz	-24.74	dBm/300 MHz
Total interference power from a single transmitter at the EESS receiver	-165.46	dBm/300 MHz	-166.78	dBm/300 MHz
Number of Simultaneous Transmitters Allowed within the EESS Pixel Size	1,326		1,796	
Effective number of base stations	530		719	
Implied base station radius	382	meters	328	meters

Table 2: Results of EESS Protection Calculations at 32 GHz

In this case, the number of mobiles is slightly greater than the number of base station sectors. Given the conservative assumptions chosen for purposes of this analysis, therefore, a maximum of

1,326 sectors can be deployed in any 201 square kilometer circular area to meet the ITU protection threshold for both base station and mobile device out-of-band emissions.

D. DISCUSSION/CONCLUSIONS

The RAS calculation results shown above show that only a modest radius of exclusion surrounding an RAS facility is required to protect RAS. Footnote US385 in the Table of Allocations defines protection zones around 16 radio astronomy locations, and the distances calculated in this analysis are smaller than these zones. This suggests that 5G services can easily coexist with radio astronomy through a combination of exclusion zones and coordination.

As stated above, the number of base stations can increase if the attenuation in the direction of the EESS satellite can be increased. This increase in attenuation can happen, for example, through power reduction (which will decrease both fundamental emissions and OOBE), greater antenna discrimination, additional filtering, or overhead gain suppression. Given the greater flexibility of controlling harmful emissions from base stations, the interference from mobile stations can be viewed as dominating the analysis. Thus, if operators use methods to further reduce harmful emissions from base stations than assumed in this analysis, the number of simultaneously transmitting base stations will be limited by the number of simultaneously transmitting mobile devices.

The results of the EESS analysis suggest that 5G deployments in the 32 GHz band will be subject to some constraints to fully protect EESS receivers. However, the nature of these constraints are not onerous and do not provide a valid reason not to allocate the band for 5G mobile services. First, the constraints affect only the first adjacent channel in the band plan; other channels in the band plan shown above would not be subject to any constraints necessary to provide sufficient margin to protect RAS against the potential for harmful interference from 5G operations. Second, the cell site density represented by the results is highly unlikely to occur in the vast majority of regions throughout the country. The cell site density required to cause harmful interference to EESS is only possible in a few of the most densely populated areas of the country, which means the constraints are unlikely to prove meaningful to 5G operators outside of a handful of highly urbanized areas.

V. 47 GHz Band (47.2 – 50.2 GHz)

A. BACKGROUND, BAND PLAN, AND FURTHER NOTICE QUESTIONS

In the 47 GHz Band, the FCC has proposed a three gigahertz band for 5G services comprised of six, 500-megahertz wide channels. The majority of the band does not border any type of passive service,[104] but the uppermost portion of the highest frequency channels shares a band edge at 50.2 GHz with two hundred megahertz allocation for EESS and space research services from 50.2 GHz to 50.4. GHz.[105] The diagram below shows the proposed band plan; passive services appear in yellow.

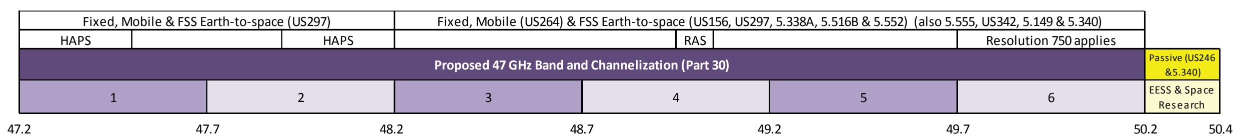


Figure 11: 47 GHz Band Plan

While there are primary non-Federal fixed and mobile broadband allocations throughout the 47 GHz band, there are currently no service rules for terrestrial operations in this band.[106] The FCC sought comment on sharing with co-primary Federal services in the 48.2-50.2 GHz band, as well as protection of passive services in the adjacent 50.2-50.4 GHz band; the FCC noted that it understood that there are currently no authorized Federal or non-Federal operations in the 48.2-50.2 GHz band but that there may be future Federal operations in that band.[107]

In considering its proposed allocation for the 47 GHz band, the FCC asked what steps, if any, should be taken to protect radio astronomy over and above implementing the existing prohibition on aeronautical use in the 48.94-49.04 GHz band.[108] The FCC also asked what requirements would be appropriate to protect passive EESS in the 50.2-50.4 GHz bands from fixed and mobile use in the 47.2-50.2 GHz band.[109]

The FCC should adopt exclusion or coordination zones to ensure protection of RAS from terrestrial service emissions in the 48.94-49.04 GHz band based on information from CORF and other radio astronomy interests on locations where the band is used for radio astronomy observations. The calculations below show that the adjacent 500 megahertz channel in the 47 GHz band plan will pose about the same challenges to protect EESS and SRS as the adjacent 200 megahertz channel in the 32 GHz band. The FCC should work with NASA and other EESS and SRS interests to analyze and develop requirements to mitigate emissions toward satellite receivers. Finally, the FCC asked whether there is any value in establishing a guard band immediately below 52.6 GHz to protect passive services immediately above 52.6 GHz.[110] The use of guard bands to protect passive EESS in adjacent bands may not be beneficial given the demonstrated characteristics of unwanted emissions from LTE technology. While 5G technology may decrease unwanted emission levels, increasing the benefit created by guard bands, available spectrum would be lost. The wireless industry should work with EESS operators to study emissions seen by satellite passive sensors and develop appropriate measures to ensure compatible operations.

B. PROTECTION OF EESS & SRS

1. CALCULATIONS

The EESS protection calculations for the 47 GHz band are very similar to those for 32 GHz with only a few exceptions. Obviously, for calculating free space loss, the higher frequency of the adjacent passive band results in a few dB more in path loss. Also, the passive band that is adjacent to the 47 GHz band is only 200 MHz wide, so the receiver bandwidth used in the 47 GHz calculations is 200 MHz rather than 300 MHz as in the 32 GHz band calculations. As described previously, this increases the power spectral density of the interference power in the passive band. Finally, as shown in the band plan above, the proposed channelization for the 47 GHz band includes 500 MHz channels, so the out-of-band roll-off of a 200 MHz 5G transmission does not apply. Further scaling of out-of-band power was required to accurately reflect the OOBE created by 5G base stations and mobile devices transmitting in 500 MHz of bandwidth. This linear scaling for 500 MHz base station and mobile emissions into a 200 MHz receiver bandwidth is shown in Figures 12 and 13 below:

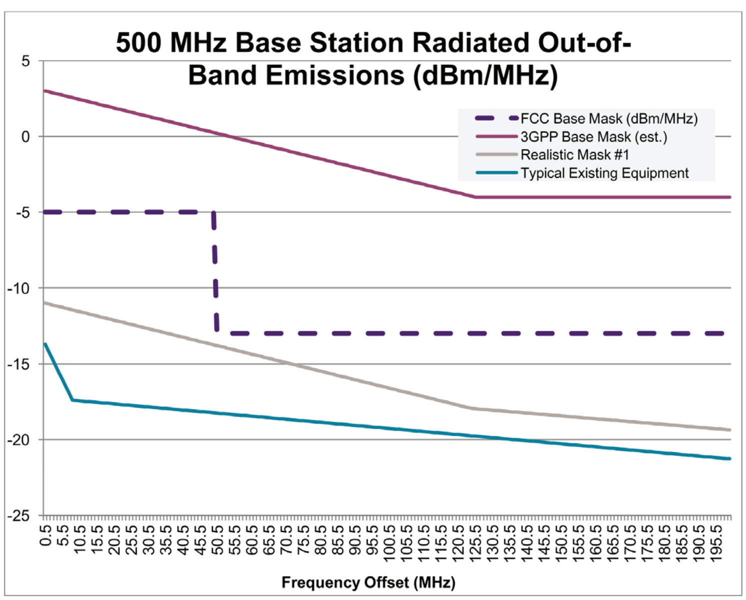


Figure 12: Base Station OOBE from a 500 MHz Transmission into 200 MHz

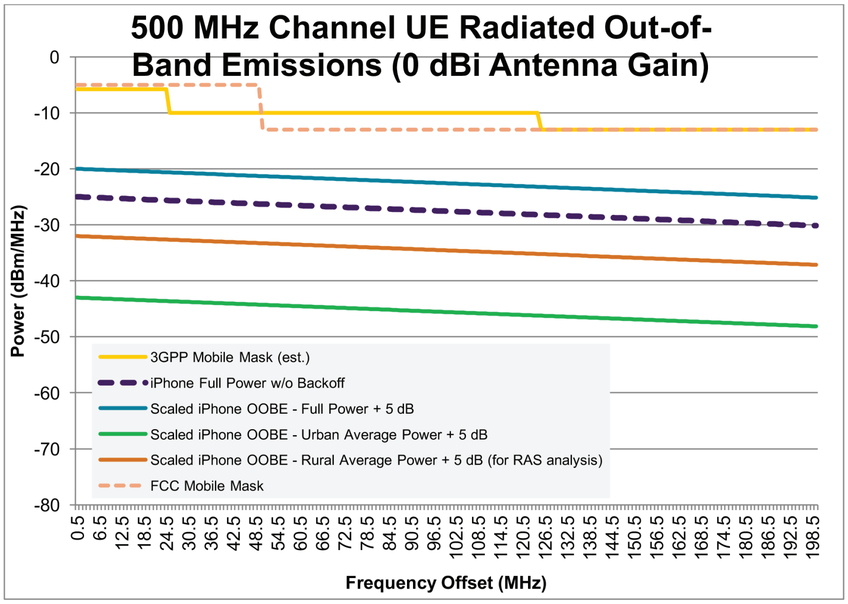


Figure 13: Mobile Device OOBE from a 500 MHz Transmission into 200 MHz

Considering these differences, the calculation methodology is identical to that described above for the 32 MHz band.

2. RESULTS

The results of the EESS protection calculations for the 47 GHz band are shown in Table 3 below:

	EESS Base		EESS UE	
	Value	Units	Value	Units
OOBE Power in EESS Receiver Bandwidth	7.77	dBm/200 MHz	-22.30	dBm/200 MHz
Total interference power from a single transmitter at the EESS receiver	-167.18	dBm/200 MHz	-168.37	dBm/200 MHz
Number of Simultaneous Transmitters Allowed within the EESS Pixel Size	1,311		1,727	
Effective number of base stations	525		691	
Implied base station radius	384	meters	335	meters

Table 3: Results of EESS Protection Calculations at 47 GHz

As expected, the out-of-band interference power is higher than in the 32 GHz band due to the slower roll-off from a 500 megahertz 5G transmission. However, this 2 dB increase is offset by about 4 dB of additional propagation losses at 50 GHz compared to 32 GHz such that the power from a single transmitter at the EESS receiver is lower. Nonetheless, the 200 megahertz receiver bandwidth also contributes to the difference because the ITU threshold is no longer scaled to a

300 megahertz receiver bandwidth. The result is that 500 megahertz channels in the 47 GHz band have approximately the same effect on EESS receivers as 200 megahertz channels in the 32 GHz band.

C. DISCUSSION/CONCLUSIONS

The calculations above show that the adjacent 500 megahertz channel in the 47 GHz band plan will have about the same challenges to protect EESS as the adjacent 200 megahertz channel in the 32 GHz band.

VI. 50 GHz Band (50.4 – 52.6 GHz)

A. BACKGROUND, BAND PLAN, AND FURTHER NOTICE QUESTIONS

In the 50 GHz band, the FCC proposed to allocate 2200 megahertz of spectrum for 5G wireless use. The band would be divided evenly among 11 two hundred megahertz-wide channels. Primary Federal allocations for the fixed and mobile services exist in the 50 GHz band, but are limited to military systems.[111] And while there are primary fixed and mobile service allocations throughout this band subject to certain restrictions, there are currently no other service rules for this band.[112] In the 50.4-50.9 GHz band, for FSS earth stations, the unwanted emissions power in the band 50.2-50.4 GHz shall not exceed -20 dBW/200 MHz.[113] In the 51.4-52.6 GHz band, unwanted emissions power into the adjacent 52.6-54.25 GHz shall not exceed – 33 dBW/100 MHz (measured at the input of the antenna).[114]

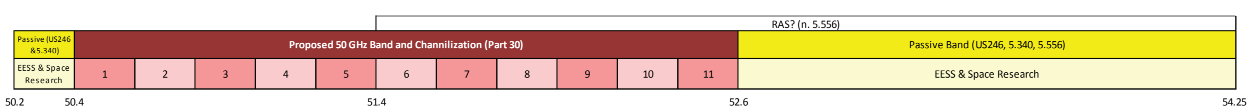


Figure 14: 50 GHz Band Plan

Passive services bookend both the lower and upper portions of the 50 GHz band. Below 50.4 GHz, the primary EESS and Space Research allocation has a primary allocation. Above 52.6 GHz, there is a co-primary EESS allocation with the SRS in 52.6-54.25 GHz band, and no station is authorized to transmit in the band.

B. PROTECTION OF EESS & SRS AT 50.4 GHZ

1. CALCULATIONS

The passive band at the lower end of the 50 GHz band is the same passive band we analyzed in the 47 GHz band section above. Therefore, we must consider the aggregate effects of interference power originating from both sides of the 50.2-50.4 GHz band. Our calculations consider the effects of the two bands independently; however, if both bands are allocated for 5G mobile use, protection of EESS passive services in the 50.2-50.4 GHz band must be addressed by considering the aggregate effects of emissions in both bands. This combination of effects may result in addition constraints on 5G deployments that use the adjacent channel in one or both bands.

The calculations for emissions in the 50 GHz band to protect EESS in the 50.2-50.4 GHz band are identical to those described above for 47 GHz except that the channel bandwidth used is 200 megahertz, consistent with the FCC's proposed channelization in the 50 GHz band.

2. RESULTS

The results of the EESS protection calculations for the 50 GHz band into the 50.2-50.4 GHz passive band are shown in Table 4 below:

	EESS Base		EESS UE	
	Value	Units	Value	Units
OOBE Power in EESS Receiver Bandwidth	5.06	dBm/200 MHz	-24.92	dBm/200 MHz
Total interference power from a single transmitter at the EESS receiver	-169.90	dBm/200 MHz	-170.98	dBm/200 MHz
Number of Simultaneous Transmitters Allowed within the EESS Pixel Size	2,452		3,151	
Effective number of base stations	981		1261	
Implied base station radius	281	meters	248	meters

Table 4: Results of EESS Protection Calculations of 50.2-50.4 GHz from the 50 GHz Band

These results clearly show the beneficial effects of using smaller bandwidth channels in the adjacent band. The total OOBE power in the EESS receiver bandwidth is approximately 2.7 dB lower than shown in Table 3 for the 47 GHz band where the channelization is 500 megahertz, and the lower interference power results in nearly twice as many simultaneous transmitters allowed.

C. PROTECTION OF EESS & SRS AT 52.6 GHZ

1. CALCULATIONS

The 52.6 – 54.25 GHz passive band at the upper end of the 50 GHz band has a much larger bandwidth than the 200 megahertz 50.2-50.4 GHz passive band and therefore can support larger bandwidth EESS measurements; however, we continue to use a receiver bandwidth of 300 megahertz for our interference calculations to be conservative. Aside from the different receiver bandwidth and higher frequency, the calculations are identical to those described earlier.

2. RESULTS

The results of the EESS protection calculations for the 50 GHz band into the 52.6-54.25 GHz passive band are shown in Table 5 below:

	EESS Base		EESS UE	
	Value	Units	Value	Units
OOBE Power in EESS Receiver Bandwidth	5.46	dBm/300 MHz	-24.73	dBm/300 MHz
Total interference power from a single transmitter at the EESS receiver	-169.90	dBm/300 MHz	-171.22	dBm/300 MHz
Number of Simultaneous Transmitters Allowed within the EESS Pixel Size	3,682		4,987	
Effective number of base stations	**1473**		1995	
Implied base station radius	229	meters	197	meters

Table 5: Results of EESS Protection Calculations of 52.6-54.25 GHz from the 50 GHz Band

The results shown here are the most favorable of the three bands analyzed in this report due to the greater path loss of the higher frequency and a transmit bandwidth of 200 megahertz.

D. DISCUSSION/CONCLUSIONS

Protecting EESS passive services in the 52.6-54.25 GHz band will require the least constraints on 5G deployments of any of the three bands under consideration in this report. Protecting passive services the 50.2-50.4 GHz band from 5G operations in the 50 GHz band will need to be performed in conjunction with 5G deployments in the 47 GHz band if 5G services are allocated in both bands. Achieving sufficient protection for EESS in the 50.2-50.4 GHz band if 5G operations are deployed in both the 47 GHz and 50 GHz bands may require a small amount of guard band which would optimally be implemented at the upper end of the 47 GHz band. Alternatively, the risk of interference from OOBE could be reduced by requiring smaller bandwidth channels at the upper end of the 47 GHz band.

VII. Conclusions

Broadband deployments in the 32 GHz, 47 GHz, and 50 GHz bands can coexist with existing RAS, EESS, and other passive operations without causing harmful interference. This study uses conservative assumptions to establish the feasibility of coexistence under worst-case conditions. Real-world conditions will provide additional margin for interference avoidance. And while the FCC may need to adopt certain modest constraints on 5G deployments within certain channels of the millimeter wave bands under consideration for broadband use, the types of constraints necessary for coexistence are modest and entirely in keeping with robust nationwide 5G deployments. Propagation characteristics, deployment architectures and technical innovations in 5G systems will substantially limit the aggregate amount of out-of-band emissions passive services will experience. Authorizing the use of the 32 GHz, 47 GHz, and 50 GHz bands for 5G deployment promises to unleash the transformative potential of these bands for broadband services while protecting incumbent passive services in adjacent-channel spectrum.

End Notes

[1] See Use of Spectrum Bands Above 24 GHz for Mobile Radio Services et al., Report and Order and Further Notice of Proposed Rulemaking, 31 FCC Rcd 8014 ¶¶ 381-99, 408-23 (2016) ("Spectrum Frontiers Report and Order and Further Notice").

[2] See Amendment of Part 2 of the FCC's Rules to Realign the 76-81 GHz Band and the Frequency Range Above 95 GHz Consistent with International Allocation Changes, et al., Report and Order, 19 FCC Rcd 3212, 3214 ¶ 3 (2004) ("RAS/EESS Order"); 47 C.F.R. § 2.1.

[3] Amendment of Part 2 of the FCC's Rules, Notice of Proposed Rulemaking, 18 FCC Rcd 8347, 8349 ¶ 4 (2003) ("RAS/EESS NPRM"); see also Final Acts of the World Radiocommunication Conference (WRC-2000).

[4] See generally RAS/EESS Order.

[5] RAS/EESS Order ¶ 1.

[6] Id. ¶ 4.

[7] Recommendation ITU-R RA.769-2, Protection Criteria Used for Radio Astronomical Measurements (2003).

[8] RAS/EESS Order ¶ 13 ("RAS receivers are usually located on high mountains or in remote areas, and access to RAS telescopes is controlled at distances of at least one kilometer").

[9] See generally RAS/EESS Order.

[10] The committee also acts as a channel for representing the interests of U.S. scientists in the work of the Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science ("IUCAF") of the International Council for Science and in working groups of the Radiocommunication Sector of the International Telecommunication Union ("ITU"). See Committee on Radio Frequencies (CORF), The National Academies of Sciences, Engineering, Medicine, http://bit.ly/2vgQzUe (last visited July 27, 2017) ("CORF Overview"); See Comments of the National Academy of Sciences' Committee on Radio Frequencies, WT Docket No. 14-177 et al., at 2 (filed Sept. 29, 2017) ("CORF Comments").

[11] See CORF Comments at 4.

[12] See id. at 8.

13 See id.

[14] See 47 C.F.R. § 2.106.

[15] In the Matter of Use of Spectrum Bands Above 24 GHz for Mobile Radio Services, Notice of Proposed Rulemaking, 30 FCC Rcd 11878 (2015) ("Spectrum Frontiers NPRM").

[16] Spectrum Frontiers Report and Order ¶¶ 5, 16; Spectrum Frontiers Further Notice ¶ 386.

[17] Spectrum Frontiers Further Notice ¶ 389.

[18] See, e.g., Comments of Avanti Communications Group PLC, GN Docket No. 14-177 et al., at 7 (filed Jan. 27, 2016) ("We appreciate that the NPRM has opened consideration to the [32 GHz band] – which was the most commonly supported band during the WRC-15 for IMT/5G – as a suitable candidate band for [international mobile telecommunications and 5G] services. . . . It is expected that such the 32 GHz frequency range could be implemented by a single 5G mobile device that could enjoy the prospect of global roaming in around the year 2020."); Comments of the EMEA Satellite Operators Assn. (ESOA), GN Docket No. 14-177 et al., at 8-9 (Jan. 27, 2016) (supporting a mobile allocation in the 32 GHz band and explaining that "deep-space research operations in the adjacent band could easily be protected from mobile terrestrial operations in this band because such research facilities are few in number and are located in very remote areas that would provide protection from interference" and proposing that concerns regarding the lack of mobile allocation in the 32 GHz band "can be addressed following the sharing and compatibility studies approved by WRC-15 for completion prior to WRC-19"); Comments of the Global VSAT Forum, GN Docket No. 14-177 et al., at 4-5 (filed Jan. 28, 2016) ("While the [32 GHz] band is not globally harmonized as a mobile band, the decision of the WRC-15 to support this band indicates that global harmonization is possible.").

[19] Spectrum Frontiers Further Notice ¶ 386.

[20] Id.

[21] The Table of Allocations indicates that RAS observations are made in the 31.3-31.8 GHz band. Although the table also indicates that RAS observations may be carried out under national arrangements in the 51.4-54.25 GHz band, we are not aware of any such use in the United States. See 47 C.F.R. § 2.106 n.5.556. The FCC does not acknowledge any RAS operations in the 50 GHz band. See Spectrum Frontiers Further Notice ¶¶ 418-423. The 51.4-52.6 GHz band is allocated for Fixed and Mobile services on a co-primary basis and unwanted emissions power is limited to -33 dBW/100 MHz (measured at the input of the antenna). See 47 C.F.R. § 2.106 US157. The 52.6-54.25 GHz band is allocated for EESS (passive) and SRS (passive) on a co-primary basis and no station is authorized to transmit in the band except for medical telemetry equipment and white space devices. See id. US246.

[22] Recommendation ITU-R RA.769-2, Protection Criteria Used for Radio Astronomical Measurements (2003) ("ITU-R RA.769-2").

[23] Id. at Recommendation 3.

[24] Id. at Recommendation 4.

[25] Id. at Annex 1, Table 1.

[26] Id.

[27] Id.

[28] In another coexistence study submitted in this docket, Reed Engineering assumed that up to 25% of radio resources are used for sector (cell)-wide non-beamformed transmission at a regular power level. See Co-Existence of 5G Mobile Service and RAS, EESS, and SRS at 31 GHz, at 5, Appendix II (2017), attached to letter from Michele C. Farquhar, counsel to Nextlink Wireless, LLC, to Marlene H. Dortch, Secretary, FCC, GN Docket No. 14-177 et al. (filed Apr. 20, 2017) (Reed Report) ("Radio resources undergoing user-specific beamforming: 75 percent (i.e., no beamforming for 25 percent of resources carrying overhead such as Reference Signals used for cell acquisition).").

[29] Reed Engineering made this assumption based on LTE standards being developed by 3GPP, a partnership of seven telecommunications standard development organizations. See About 3GPP, 3GPP, http://bit.ly/1bKDd48 (last visited Aug. 2, 2017). In its RAS and EESS exclusion zone calculations for macrocells with beamforming, Reed Engineering relied on an LTE example in which reference signals comprised less than 20% of air-interface resources, and also assumes that 5G transmitter overhead signals will contribute less than 25% to interference. See Reed Report at Appendix II at 1.

[30] Nokia, for example, identified the antenna discrimination from 5G base stations toward geosynchronous satellites at a look angle of 15 degrees as 48 dB and does not separate losses for beam-formed signals from losses for non-beamformed signals. See Letter from Stacey Black et al. to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 3 (filed June 1, 2016), http://bit.ly/2vLPWhQ.

[31] See Spectrum Frontiers Further Notice ¶ 399.

[32] Although this is mathematically true in the aggregate, scenarios may arise in which traffic distribution is not uniform and interference to RAS may be more likely. In those circumstances, coordination, detailed propagation analysis, proper site selection, and site engineering will be necessary to eliminate any possibility of interference to RAS when wireless operators deploy 5G networks that employ uplink beamforming in close proximity to RAS antennas.

[33] See National Research Council, Spectrum Management for Science in the 21st Century 114, 122 (Feb. 25, 2010), http://bit.ly/2vbiCoj.

[34] See ITU-R RA.769-2 at ¶ 1.3.

[35] RAS/EESS Order ¶ 3.

[36] Id.

[37] Id. ¶¶ 1, 3 n.3; 47 C.F.R. § 2.1.

[38] WRC-12 Resolution 750.

[39] CORF Comments at 4.

[40] Id.

[41] See Report ITU-R SM.2092 at 200.

[42] Id. at 224.

[43] See Report ITU-R SM.2092, Studies Related to the Impact of Active Services Allocated in Adjacent or Nearby Bands on Earth Exploration-Satellite Service (Passive) ¶ 9.1.3 (2007) ("ITU-R SM.2092").

[44] See Recommendation ITU-R RS.1029-2, Interference Criteria for Satellite Passive Remote Sensing (2003) (withdrawn 2012).

[45] Recommendation ITU-R RS.2017, Performance and Interference Criteria for Satellite Passive Remote Sensing (2012) ("ITU-R RS.2017").

[46] ITU-R RS.2017 at 1.

[47] ITU-R SM.2092 states in paragraph 8.3 that the interference criterion for a specific band "is the maximum permissible interference level for the passive sensor from all sources of interference." See ITU-R SM.2092 ¶ 8.3 (emphasis added). Although this report does not represent an aggregate analysis and does not consider contributions from all services that may cause interference to EESS, we believe the conservative assumptions used in the study leave sufficient headroom to account for other sources of interference.

[48] See ITU-R RS.2017 at Table 2.

[49] See ITU-R SM.2092 ¶ 9.1.4.

[50] See id.

[51] See Letter from to Jennifer A. Manner, EchoStar Corp., to Marlene H. Dortch, FCC, GN Docket No. 14-177 et al. at 7 (filed May 12, 2016).

[52] See Letter from to Gregory M. Romano, Verizon, to Marlene H. Dortch, FCC, GN Docket No. 14-177 et al. at 2 (filed May 19, 2016).

[53] Nokia calculates that the antenna discrimination from a 5G UE to a geosynchronous satellite is 22 dB. See Presentation: FSS and 5G Coexistence Analysis at 28 GHz System-level Simulation Results at 21 (Exhibit 2 to Letter from to Prakash Moorut, Nokia et al., to Marlene H. Dortch, FCC, GN Docket No. 14-177 et al. at 7 (filed May 12, 2016). This calculation may be a more reasonable assumption for antenna discrimination in the zenith direction.

[54] This analysis does not consider indoor base stations as contributing factors to interference analysis. In the case of EESS, the satellite is directly overhead; therefore, signals from indoor users must traverse at least a ceiling and a roof and possibly several intermediate floors, too. The attenuation from these types of barriers at frequencies as high as the millimeter wave bands prevents indoor users from contributing to the interference scenarios relevant for satellite operations. Extensive, multiparty studies support this conclusion. For example, AT&T, Ericsson, Nokia, Samsung, T-Mobile and Verizon examined interference from 5G to GSO satellites at various look angles, all of which could leave a window between a 5G user and the victim satellite. These parties jointly concluded that "indoor devices will not impact FSS at all." See Letter from Stacey Black et al., to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 (filed June 1, 2016).

[55] See Letter from Mark Racek, Ericsson, to Marlene H. Dortch, FCC, GN Docket No. 14-177, RM-11664, at 2-3 (filed June 15, 2016) ("As with LTE, Transmission Time Intervals ("TTI") are used to coordinate multiplexing and access control. . . . While the number of UEs served by a base station may number in the thousands, that number is not pertinent to the interference calculation, as interference is only generated by transmitting or "active" users (in each TTI and sector)" and "[o]ne UE will be scheduled at each frequency at a time per base station.") In Ericsson's parlance, a base station is a single sector of a cell site. See id. at 4 ("81 sites with three sectors = 243 base stations.").

[56] Multi-user MIMO (MU-MIMO) could employ Spatial Diversity Multiple Access ("SDMA") in which spatially distributed transmission resources occupy the same frequency resource blocks at the same time. While MU-MIMO SDMA deployments in the millimeter wave bands could challenge our assumption about the number of simultaneously transmitting mobile devices on any given frequency, the deployment models currently envisioned for the millimeter wave bands do not appear to contemplate MU-MIMO SDMA uplinks and, in any event, constraints on the use of MU-MIMO SDMA uplinks could be imposed to ensure the number of simultaneously transmissions on any given frequency remains limited. Given the highly conservative nature of our assumptions, however, the necessity of constraints on MU-MIMO SDMA should be viewed skeptically.

[57] FCC OET, Tutorial on TDD Systems, Part 1: Overview of Duplex Schemes (2001), http://bit.ly/2vgQzUe.

[58] Id. at 5.

[59] See National Advanced Spectrum and Communications Test Network (NASCTN), Draft AWS-3 Out of Band Emissions Measurements, Test and Methodology Phase II Test Plan, at 12 (Oct. 11, 2016) ("NASCTN AWS-3 OOBE Report"), http://bit.ly/2tXA67K ("It is sometimes suggested that emission measurements are not needed because it can be assumed that transmitters operate at their required emission mask limits. This assumption is nearly always false. Transmitter out-of-band (OOB) and spurious emissions are usually substantially lower than emission mask limits, often by tens of decibels. Interference studies that assume that transmitter emissions are as high as emission mask limits will therefore overestimate the power levels of most transmitters' OOB and spurious emissions. As a result, required frequency and distance separations needed for compatible operations between systems will also be overestimated.").

[60] Id.

[61] Id.

[62] Some recent FCC emissions masks, including the masks used for mobile and base station emissions used in this study, see infra Sections IV.B, V.B, and VI.B. FCC OOBE limits that may appear more stringent than OOBE limits of 3GPP. The seemingly more stringent FCC limits are illusory. In the millimeter wave bands, the FCC uses a methodology for determining out-of-band emissions that employs a more lenient limit within ten percent of the transmit bandwidth. The 3GPP limits do not calculate OOBE in the same manner, but use limits scaled from the twenty-megahertz LTE emissions mask. The two limits not related: the FCC's approach is specific to the millimeter wave bands, and the 3GPP approach is specific to the limits associated with 4G LTE in bands below 6 GHz bands.

[63] See Spectrum Frontiers Further Notice ¶¶ 399, 423.

[64] See id. ¶ 417.

[65] See Spectrum Frontiers Report and Order ¶¶ 301-305 (setting the OOBE limit for both conductive metric and TRP metric to -13 dBm/MHz).

[66] Spectrum Frontiers Further Notice ¶ 303.

[67] Id. ¶ 301.

[68] Id.

[69] Id.

[70] Letter from Dean Brenner, Qualcomm Incorporated, to Marlene Dortch, FCC, GN Docket No. 12-354, at 3 (filed June 19, 2017).

[71] The 5G New Radio ("NR") waveform is expected to be based on Orthogonal Frequency Division Multiplexing or OFDM, just like LTE. The subcarrier bandwidth in NR will be scalable as opposed to fixed as it is today in LTE. The high likelihood of 5G NR standard employing scalable, OFDM makes 4G LTE OOBE performance a reliable proxy for 5G OOBE performance after accounting for changes in bandwidth, frequency and other factors.

[72] 3GPP, Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) Radio Transmission and Reception: Specification # 36.101 (LTE).

[73] UL Verification Services Inc., Certification Test Report No. 15U21635-E9V3, FCC ID: BCG-E3042A, for Cellular Phone with Bluetooth and WLAN Radios, at 520 (Feb. 4, 2016), http://bit.ly/2vaOgm8.

[74] See, e.g., FCC, Equipment Authorization System, FCC ID BCG-E3042A, OET Exhibits List, http://bit.ly/2vaOgm8.

[75] See CSMAC Final Report, Working Group 1 – 1695-1710 MHz Meteorological-Satellite, at Appendix 3 (Jan. 22, 2013) ("CSMAC Report"), http://bit.ly/2vbPD3Y.

[76] See NTIA, CSMAC, http://bit.ly/2f2kOly.

[77] See CSMAC Report at Appendix 3.

[78] See id.

[79] The maximum power assumed in the CSMAC simulations was 20 dBm, whereas 3GPP standards typically allow a maximum power level of 23 dBm. The difference is 20-(-3) = 23 dB but one could also realistically assume that UE power levels between 20 and 23 dBm will be rare such that the 50% point does not change. Thus a calculated difference of 23-(-3) = 26 dB is also reasonable. To be conservative we have assumed a difference of 23 dB.

[80] See, e.g., NASCTN AWS-3 OOBE Report at 27 ("The relative offsets in measured power between a transmitter's fundamental frequency and its 582 OOBE will vary as a function of the resolution bandwidth and measurement detector mode. The amount of this variation is ultimately determined by the modulation of the transmitter's emissions.").

[81] See Ericsson Study at 5 (showing a maximum conducted power for 5G mobile devices of 26 dBm and a 50% operating point of -5 dBm). The difference is 31 dB.

[82] Id. at 5.

[83] See discussion supra Section III.B.

[84] See R.N. Electronics Ltd., Radio Test Report: Cambridge Communication Systems Ltd., Metnet V4 Report No. 08-8048-2-15, at 55 (Aug. 2015), http://bit.ly/2vx3H7j.

[85] The 3GPP base station specification 36.104 includes several emissions masks depending on region and channel size. The mask depicted here is based on the mask for a 20 megahertz channel using the least restrictive of the regional variants. See 3GPP, Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) Radio Transmission and Reception: Specification # 36.104 (LTE), Table 6.6.3.1-6.

[86] See Spectrum Frontiers NPRM ¶¶ 73-74.

[87] No station is currently authorized to transmit in the 31.3-31.8 GHz band. See 47 C.F.R. § 2.106 US246.

[88] Id. US262.

[89] Id. 5.548.

[90] Id. US211.

[91] Id. US211.

[92] Id. US278.

[93] Id. US69.

[94] Id. US69.

[95] Id. US360.

[96] Id. US360.

[97] Id. G117.

[98] Spectrum Frontiers Further Notice ¶ 397.

[99] See infra Section IV.D; see also Comments of the EMEA Satellite Operators Association ("ESOA"), GN Docket No. 14-177 et al., at 9 (filed Jan. 27, 2016) (urging that concerns for protecting services operating in or adjacent to the 32 GHz band "can be addressed with carefully crafted operating requirements.").

[100] See infra Section IV.D.

[101] According to ITU Recommendation SM.2092, there are two types of EESS sensors: mechanical and electrical. Mechanical sensors are used today and sequentially scan sections of the Earth, while electronic "push-broom" sensors scan a continuous swath, but are not yet deployed. The parameters used in this analysis correspond to the latter type of sensor as recommended by the ITU. See ITU-R SM.2092 at 3.1.4, 7.1.4, 7.4.2.1.2, 7.5.1, 8.1.3, 8.1.4.

[102] See ITU-R SM.2092 at 9.1.4

[103] See id. at Table 10-2

[104] The 48.94-49.04 GHz band is also used by RAS for spectral line observations, and all practicable steps must be taken to protect radio astronomy in that band from interference.47 C.F.R. § 2.106 US342.

[105] 47 C.F.R. § 2.106 US246; ITU RR 5.340.1 (the international allocation for the passive services "shall not impose undue constraints on the use of adjacent bands by the primary allocated services in those bands"). International footnote 5.556 provides that RAS observations may be carried out under national arrangements in the 51.4-54.25 GHz band. See 47 C.F.R. § 2.106 n.5.556.

[106] See Spectrum Frontiers Further Notice ¶ 408.

[107] See id. ¶ 416.

[108] See id.

[109] See id.

[110] See Spectrum Frontiers Further Notice ¶ 423.

[111] 47 C.F.R. § 2.106 G117.

[112] Spectrum Frontiers Further Notice ¶ 418.

[113] 47 C.F.R. § 2.106 US 156. Maximum unwanted emissions power may be increased to -10 dBW/200 MHz for earth stations having an antenna gain greater than or equal to 57 dBi. These limits apply under clear-sky conditions. During fading conditions, the limits may be exceeded by earth stations when using uplink power control.

[114] See 47 CFR § 2.106 n.US157.

[115] 47 C.F.R. § 2.106 US246.

APPENDIX A

DETAILED CALCULATIONS

RAS Protection from 32 GHz Base Stations

RAS Protection Criteria

Parameter	Value	Units	Source
ITU Interference Threshold	-192.0	dBW/500 MHz	ITU-R RA.769-2, Table 1
ITU Interference Threshold	-162.0	dBm/500 MHz	
ITU Threshold per RAS Bandwidth	-164.2	dBm/300 MHz	

RAS Parameters

Parameter	Value	Units	Source
RAS Rx Bandwidth	300	MHz	Smaller Rx BW are worst case so assuming RAS is receiving in 31.5-31.8 GHz is conservative
RAS Center Frequency	31.65	GHz	Center frequency of the closest 300 GHz RAS receive channel
RAS side lobe antenna gain	0	dBi	ITU-R RA.769-2, para. 1.3

5G Transmitter Parameters

Parameter	Value	Units	Source
5G Base Station Tx Bandwidth	200	MHz	Per FCC proposed channelization
OOBE Power in the RAS receive band	5.46	dBm/300 MHz	Per realistic OOBE model
Percent RF resources needed for control (no beamforming)	25%		Same as Reed paper
Antenna discrimination toward RAS receiver for non-beamformed RF	15	dB	Same as Reed paper
Antenna discrimination toward RAS receiver for beamformed RF	40	dB	Same as Reed paper
Interference contribution of non-beamformed RF	0.0278	mW	
Interference contribution of beamformed RF	0.0003	mW	
Total interference power	0.0281	mW	
Total Interference power	-15.52	dBm/300 MHz	
Simultaneous transmitting base stations	3		
Aggregate interference power	-10.74	dBm/300 MHz	

Separation Requirement

Parameter	Value	Units	Source
Total required path loss	153.5	dB	Ix Power (in 300 MHz) - Protection Threshold (in 300 MHz)+RAS gain
Free space path loss distance	**35.5**	**km**	

RAS Protection from 32 GHz Mobile Devices

RAS Protection Criteria

Parameter	Value	Units	Source
ITU Interference Threshold	-192.0	dBW/500 MHz	ITU-R RA.769-2, Table 1
ITU Interference Threshold	-162.0	dBm/500 MHz	
ITU Threshold per RAS Bandwidth	-164.2	dBm/300 MHz	

RAS Parameters

Parameter	Value	Units	Source
RAS Rx Bandwidth	300	MHz	Smaller Rx BW are worst case so assuming RAS is receiving in 31.5-31.8 GHz is conservative
RAS Center Frequency	31.65	GHz	Center frequency of the closest 300 GHz RAS receive channel
RAS side lobe antenna gain	0	dBi	ITU-R RA.769-2, para. 1.3

5G Transmitter Parameters

Parameter	Value	Units	Source
5G Base Station Tx Bandwidth	200	MHz	Per FCC proposed channelization
OOBE Power in the RAS receive band	-13.74	dBm/300 MHz	iPhone Rural Average Power
UE antenna gain	0	dBi	
Total Interference power from one UE	-13.74	dBm/300 MHz	

UE Limit Requirement Based on BTS Distance

Parameter	Value	Units	Source
Assumed Cell Radius	1.2	km	Very conservative (large) cell radius for 5G
Other losses (e.g., antenna discrimination toward RAS receiver, clutter, foliage, terrain, etc.)	7	dB	Conservative estimate given the distance and the height from which most UEs will transmit
Total path loss based on Base Station Exclusion zone and cell radius above	153.2	dB	Free Space Path Loss
Interference power from a single UE at the RAS receiver	-173.9	dBm/300 MHz	Ix Power (in 300 MHz) - Protection Threshold (in 300 MHz)+RAS gain-Other losses
Number of simultaneous transmitting UEs at cell edge	**9.3**		Because only one UE per sector can transmit at the edge of the band at any given time, this only needs to be greater than the number of sectors

EESS Protection from 32 GHz Base Stations

EESS Protection Criteria

Parameter	Value	Units	Source
ITU Interference Threshold	-166.0	dBW/200 MHz	ITU-R RS.2017, Table 2
ITU Interference Threshold	-136.0	dBm/200 MHz	
ITU Threshold per EESS Bandwidth	-134.2	dBm/300 MHz	

EESS Parameters

Parameter	Value	Units	Source
EESS Rx Bandwidth	300	MHz	Smaller Rx BW are worst case so assuming EESS is receiving only in 31.5-31.8 GHz is conservative
EESS Center Frequency	31.65	GHz	Center frequency of the closest 300 GHz EESS receive channel
EESS Satellite altitude	850	km	ITU-R SM.2092, Para. 9.1.4
EESS Pixel size	201	km^2	ITU-R SM.2092, Para. 9.1.4
EESS antenna gain	45	dBi	ITU-R SM.2092, Para. 9.1.4

5G Transmitter Parameters

Parameter	Value	Units	Source
5G Base Station Tx Bandwidth	200	MHz	Per FCC proposed channelization
OOBE Power in EESS Receiver Bandwidth	5.46	dBm/300 MHz	Per realistic OOBE model
Percent RF resources needed for control (no beamforming)	25%		Same as Reed paper
Antenna discrimination toward EESS receiver for non-beamformed RF	30	dB	
Antenna discrimination toward RAS receiver for beamformed RF	40	dB	Same as Reed paper
Interference contribution of non-beamformed RF	0.0009	mW	
Interference contribution of beamformed RF	0.0003	mW	
Total interference power	0.0011	mW	
Total Interference power from a single sector	-29.4	dBm/300 MHz	
Free space loss between earth and satellite	181.0	dB	
Total interference power from a single sector at the EESS receiver	-165.5	dBm/300 MHz	Total interference power - path loss + EESS antenna gain
Number of Simultaneous Transmitting Sectors Allowed within the EESS Pixel Size	**1326**		
Average number of sectors per cell	2.5		Assume some omnis and two-sector sites for an average of 2.5 sectors per site
Number of base stations	**530**		
Average area covered per cell	0.38	km^2	
Hexagonal Cell Radius	382	meters	

EESS Protection from 32 GHz Mobile Devices

EESS Protection Criteria

Parameter	Value	Units	Source
ITU Interference Threshold	-166.0	dBW/200 MHz	ITU-R RS.2017, Table 2
ITU Interference Threshold	-136.0	dBm/200 MHz	
ITU Threshold per EESS Bandwidth	-134.2	dBm/300 MHz	

EESS Parameters

Parameter	Value	Units	Source
EESS Rx Bandwidth	300	MHz	Smaller Rx BW are worst case so assuming EESS is receiving only in 31.5-31.8 GHz is conservative
EESS Center Frequency	31.65	GHz	Center frequency of the closest 300 GHz EESS receive channel
EESS Satellite altitude	850	km	ITU-R SM.2092, Para. 9.1.4
EESS Pixel size	201	km^2	ITU-R SM.2092, Para. 9.1.4
EESS antenna gain	45	dBi	ITU-R SM.2092, Para. 9.1.4

5G Transmitter Parameters

Parameter	Value	Units	Source
5G Base Station Tx Bandwidth	200	MHz	Per FCC proposed channelization
OOBE Power in EESS Receive Band	-24.74	dBm/300 MHz	iPhone Urban Average Power
Antenna discrimination at zenith	6	dB	Very conservative since antenna discriminatiuon at zenith is likely 22 dB or more and there will likely be additional losses
Total interference power from a single UE	-30.74	dBm/300 MHz	

Simultaneous UE Transmitters Requirement

Free space loss between earth and satellite	181.0	dB	
Total interference power from a single UE at the EESS receiver	-166.8	dBm/300 MHz	Interference power - free space path loss + EESS antenna gain
Number of Simultaneous Transmitting UEs Allowed within the EESS Pixel Size	**1,796**		Only one UE can transmit to a sector at the edge of the band at any given time, so this becomes the upper limit on the number of sectors

EESS Protection from 47 GHz Base Stations

EESS Protection Criteria

Parameter	Value	Units	Source
ITU Interference Threshold	-166.0	dBW/200 MHz	ITU-R RS.2017, Table 2
ITU Interference Threshold	-136.0	dBm/200 MHz	
ITU Threshold per EESS Bandwidth	-136.0	dBm/200 MHz	

EESS Parameters

Parameter	Value	Units	Source
EESS Rx Bandwidth	200	MHz	Smaller Rx BW are worst case so assuming EESS is receiving only in 50.2-50.4 GHz is conservative
EESS Center Frequency	50.3	GHz	Center frequency of the closest 200 GHz EESS receive channel
EESS Satellite altitude	850	km	ITU-R SM.2092, Para. 9.1.4
EESS Pixel size	201	km^2	ITU-R SM.2092, Para. 9.1.4
EESS antenna gain	45	dBi	ITU-R SM.2092, Para. 9.1.4

5G Transmitter Parameters

Parameter	Value	Units	Source
5G Base Station Tx Bandwidth	500	MHz	Per FCC proposed channelization
OOBE Power in EESS Receiver Bandwidth	7.77	dBm/200 MHz	Per realistic OOBE model
Percent RF resources needed for control (no beamforming)	25%		Same as Reed paper
Antenna discrimination toward EESS receiver for non-beamformed RF	30	dB	
Antenna discrimination toward RAS receiver for beamformed RF	40	dB	Same as Reed paper
Interference contribution of non-beamformed RF	0.0015	mW	
Interference contribution of beamformed RF	0.0004	mW	
Total interference power	0.0019	mW	
Total Interference power from a single sector	-27.1	dBm/200 MHz	
Free space loss between earth and satellite	185.1	dB	
Total interference power from a single sector at the EESS receiver	-167.2	dBm/200 MHz	Total interference power - path loss + EESS antenna gain
Number of Simultaneous Transmitting Sectors Allowed within the EESS Pixel Size	1311		
Average number of sectors per cell	2.5		Assume some omnis and two-sector sites for an average of 2.5 sectors per site
Number of base stations	**525**		
Average area covered per cell	0.38	km^2	
Hexagonal Cell Radius	384	meters	

EESS Protection from 47 GHz Mobile Devices

EESS Protection Criteria

Parameter	Value	Units	Source
ITU Interference Threshold	-166.0	dBW/200 MHz	ITU-R SM.2092, Table 2
ITU Interference Threshold	-136.0	dBm/200 MHz	
ITU Threshold per EESS Bandwidth	-136.0	dBm/300 MHz	

EESS Parameters

Parameter	Value	Units	Source
EESS Rx Bandwidth	200	MHz	Smaller Rx BW are worst case so assuming EESS is receiving only in 31.5-31.8 GHz is conservative
EESS Center Frequency	50.3	GHz	Center frequency of the closest 300 GHz EESS receive channel
EESS Satellite altitude	850	km	ITU-R SM.2092, Para. 9.1.4
EESS Pixel size	201	km^2	ITU-R SM.2092, Para. 9.1.4
EESS antenna gain	45	dBi	ITU-R SM.2092, Para. 9.1.4

5G Transmitter Parameters

Parameter	Value	Units	Source
5G Base Station Tx Bandwidth	500	MHz	Per FCC proposed channelization
OOBE Power in EESS Receive Band	-22.30	dBm/200 MHz	iPhone Urban Average Power
Other losses (UE antenna discrimination toward EESS receiver, clutter, atmospheric absorption, etc.)	6	dB	Very conservative since many UEs will likely have additional losses that greatly exceed the assumption
Total interference power from a single UE	-28.30	dBm/300 MHz	

Simultaneous UE Transmitters Requirement

Free space loss between earth and satellite	185.1	dB	
Total interference power from a single UE at the EESS receiver	-168.4	dBm/300 MHz	Interference power - free space path loss + EESS antenna gain
Number of Simultaneous Transmitting UEs Allowed within the EESS Pixel Size	**1,727**		Only one UE can transmit to a sector at the edge of the band at any given time, so this becomes the upper limit on the number of sectors

EESS Protection of 50.2-50.4 GHz from 50 GHz Base Stations

EESS Protection Criteria

Parameter	Value	Units	Source
ITU Interference Threshold	-166.0	dBW/200 MHz	ITU-R RS.2017, Table 2
ITU Interference Threshold	-136.0	dBm/200 MHz	
ITU Threshold per EESS Bandwidth	-136.0	dBm/200 MHz	

EESS Parameters

Parameter	Value	Units	Source
EESS Rx Bandwidth	200	MHz	Smaller Rx BW are worst case so assuming EESS is receiving only in 31.5-31.8 GHz is conservative
EESS Center Frequency	50.3	GHz	Center frequency of the closest 300 GHz EESS receive channel
EESS Satellite altitude	850	km	ITU-R SM.2092, Para. 9.1.4
EESS Pixel size	201	km^2	ITU-R SM.2092, Para. 9.1.4
EESS antenna gain	45	dBi	ITU-R SM.2092, Para. 9.1.4

5G Transmitter Parameters

Parameter	Value	Units	Source
5G Base Station Tx Bandwidth	200	MHz	Per FCC proposed channelization
OOBE Power in EESS Receiver Bandwidth	5.06	dBm/200 MHz	Per realistic OOBE model
Percent RF resources needed for control (no beamforming)	25%		Same as Reed paper
Antenna discrimination toward EESS receiver for non-beamformed RF	30	dB	
Antenna discrimination toward RAS receiver for beamformed RF	40	dB	Same as Reed paper
Interference contribution of non-beamformed RF	0.0008	mW	
Interference contribution of beamformed RF	0.0002	mW	
Total interference power	0.0010	mW	
Total Interference power from a single sector	-29.8	dBm/200 MHz	
Free space loss between earth and satellite	185.1	dB	
Total interference power from a single sector at the EESS receiver	-169.9	dBm/200 MHz	Total interference power - path loss + EESS antenna gain
Number of Simultaneous Transmitting Sectors Allowed within the EESS Pixel Size	**2452**		
Average number of sectors per cell	2.5		Assume some omnis and two-sector sites for an average of 2.5 sectors per site
Number of base stations	**981**		
Average area covered per cell	0.20	km^2	
Hexagonal Cell Radius	281	meters	

EESS Protection at 50.2-50.4 GHz from 50 GHz Mobile Devices

EESS Protection Criteria

Parameter	Value	Units	Source
ITU Interference Threshold	-166.0	dBW/200 MHz	ITU-R SM.2092, Table 2
ITU Interference Threshold	-136.0	dBm/200 MHz	
ITU Threshold per EESS Bandwidth	-136.0	dBm/300 MHz	

EESS Parameters

Parameter	Value	Units	Source
EESS Rx Bandwidth	200	MHz	Smaller Rx BW are worst case so assuming EESS is receiving only in 31.5-31.8 GHz is conservative
EESS Center Frequency	50.3	GHz	Center frequency of the closest 300 GHz EESS receive channel
EESS Satellite altitude	850	km	ITU-R SM.2092, Para. 9.1.4
EESS Pixel size	201	km^2	ITU-R SM.2092, Para. 9.1.4
EESS antenna gain	45	dBi	ITU-R SM.2092, Para. 9.1.4

5G Transmitter Parameters

Parameter	Value	Units	Source
5G Base Station Tx Bandwidth	200	MHz	Per FCC proposed channelization
OOBE Power in EESS Receive Band	-24.92	dBm/200 MHz	iPhone Urban Average Power
Other losses (UE antenna discrimination toward EESS receiver, clutter, atmospheric absorption, etc.)	6	dB	Very conservative since many UEs will likely have additional losses that greatly exceed the assumption
Total interference power from a single UE	-30.92	dBm/300 MHz	

Simultaneous UE Transmitters Requirement

Free space loss between earth and satellite	185.1	dB	
Total interference power from a single UE at the EESS receiver	-171.0	dBm/300 MHz	Interference power - free space path loss + EESS antenna gain
Number of Simultaneous Transmitting UEs Allowed within the EESS Pixel Size	**3,151**		Only one UE can transmit to a sector at the edge of the band at any given time, so this becomes the upper limit on the number of sectors

EESS Protection of 52.6-54.25 GHz from 50 GHz Base Stations

EESS Protection Criteria

Parameter	Value	Units	Source
ITU Interference Threshold	-166.0	dBW/200 MHz	ITU-R RS.2017, Table 2
ITU Interference Threshold	-136.0	dBm/200 MHz	
ITU Threshold per EESS Bandwidth	-134.2	dBm/300 MHz	

EESS Parameters

Parameter	Value	Units	Source
EESS Rx Bandwidth	300	MHz	Smaller Rx BW are worst case so assuming EESS is receiving only in 31.5-31.8 GHz is conservative
EESS Center Frequency	52.75	GHz	Center frequency of the closest 300 GHz EESS receive channel
EESS Satellite altitude	850	km	ITU-R SM.2092, Para. 9.1.4
EESS Pixel size	201	km^2	ITU-R SM.2092, Para. 9.1.4
EESS antenna gain	45	dBi	ITU-R SM.2092, Para. 9.1.4

5G Transmitter Parameters

Parameter	Value	Units	Source
5G Base Station Tx Bandwidth	200	MHz	Per FCC proposed channelization
OOBE Power in EESS Receiver Bandwidth	5.46	dBm/300 MHz	Per realistic OOBE model
Percent RF resources needed for control (no beamforming)	25%		Same as Reed paper
Antenna discrimination toward EESS receiver for non-beamformed RF	30	dB	
Antenna discrimination toward RAS receiver for beamformed RF	40	dB	Same as Reed paper
Interference contribution of non-beamformed RF	0.0009	mW	
Interference contribution of beamformed RF	0.0003	mW	
Total interference power	0.0011	mW	
Total Interference power from a single sector	-29.4	dBm/300 MHz	
Free space loss between earth and satellite	185.5	dB	
Total interference power from a single sector at the EESS receiver	-169.9	dBm/300 MHz	Total interference power - path loss + EESS antenna gain
Number of Simultaneous Transmitting Sectors Allowed within the EESS Pixel Size	3682		
Average number of sectors per cell	2.5		Assume some omnis and two-sector sites for an average of 2.5 sectors per site
Number of base stations	**1473**		
Average area covered per cell	0.14	km^2	
Hexagonal Cell Radius	229	meters	

EESS Protection of 52.6-54.25 GHz from 50 GHz Mobile Devices

EESS Protection Criteria

Parameter	Value	Units	Source
ITU Interference Threshold	-166.0	dBW/200 MHz	ITU-R SM.2092, Table 2
ITU Interference Threshold	-136.0	dBm/200 MHz	
ITU Threshold per EESS Bandwidth	-134.2	dBm/300 MHz	

EESS Parameters

Parameter	Value	Units	Source
EESS Rx Bandwidth	300	MHz	Smaller Rx BW are worst case so assuming EESS is receiving only in 31.5-31.8 GHz is conservative
EESS Center Frequency	52.75	GHz	Center frequency of the closest 300 GHz EESS receive channel
EESS Satellite altitude	850	km	ITU-R SM.2092, Para. 9.1.4
EESS Pixel size	201	km^2	ITU-R SM.2092, Para. 9.1.4
EESS antenna gain	45	dBi	ITU-R SM.2092, Para. 9.1.4

5G Transmitter Parameters

Parameter	Value	Units	Source
5G Base Station Tx Bandwidth	200	MHz	Per FCC proposed channelization
OOBE Power in EESS Receive Band	-24.73	dBm/300 MHz	iPhone Urban Average Power
Other losses (UE antenna discrimination toward EESS receiver, clutter, atmospheric absorption, etc.)	6	dB	Very conservative since many UEs will likely have additional losses that greatly exceed the assumption
Total interference power from a single UE	-30.73	dBm/300 MHz	

Simultaneous UE Transmitters Requirement

Free space loss between earth and satellite	185.5	dB	
Total interference power from a single UE at the EESS receiver	-171.2	dBm/300 MHz	Interference power - free space path loss + EESS antenna gain
Number of Simultaneous Transmitting UEs Allowed within the EESS Pixel Size	**4,987**		Only one UE can transmit to a sector at the edge of the band at any given time, so this becomes the upper limit on the number of sectors

APPENDIX B

RADIO ASTRONOMY LOCATIONS

The Table of Allocations defines 16 locations in which radio astronomy observations are performed in the 31.3-31.8 GHz band:

US74 In the bands 25.55-25.67, 73-74.6, 406.1-410, 608-614, 1400-1427, 1660.5-1670, 2690-2700, and 4990-5000 MHz, and in the bands 10.68-10.7, 15.35-15.4, 23.6-24.0, 31.3-31.5, 86-92, 100-102, 109.5-111.8, 114.25-116, 148.5-151.5, 164-167, 200-209, and 250-252 GHz, the radio astronomy service shall be protected from unwanted emissions only to the extent that such radiation exceeds the level which would be present if the offending station were operating in compliance with the technical standards or criteria applicable to the service in which it operates. Radio astronomy observations in these bands are performed at the locations listed in US385.

US385 Radio astronomy observations may be made in the bands 1350-1400 MHz, 1718.8-1722.2 MHz, and 4950-4990 MHz on an unprotected basis, and in the band 2655-2690 MHz on a secondary basis, at the following radio astronomy observatories:

Allen Telescope Array, Hat Creek, CA	Rectangle between latitudes 40°00′ N and 42°00′ N and between longitudes 120°15′ W and 122°15′ W.	
NASA Goldstone Deep Space Communications Complex, Goldstone, CA	80 kilometers (50 mile) radius centered on 35°20′ N, 116°53′ W.	
National Astronomy and Ionosphere Center, Arecibo, PR	Rectangle between latitudes 17°30′ N and 19°00′ N and between longitudes 65°10′ W and 68°00′ W.	
National Radio Astronomy Observatory, Socorro, NM	Rectangle between latitudes 32°30′ N and 35°30′ N and between longitudes 106°00′ W and 109°00′ W.	
National Radio Astronomy Observatory, Green Bank, WV	Rectangle between latitudes 37°30′ N and 39°15′ N and between longitudes 78°30′ W and 80°30′ W.	
National Radio Astronomy Observatory, Very Long Baseline Array Stations	80 kilometer radius centered on:	
	North latitude	West longitude
Brewster, WA	48°08′	119°41′
Fort Davis, TX	30°38′	103°57′
Hancock, NH	42°56′	71°59′
Kitt Peak, AZ	31°57′	111°37′
Los Alamos, NM	35°47′	106°15′
Mauna Kea, HI	19°48′	155°27′
North Liberty, IA	41°46′	91°34′
Owens Valley, CA	37°14′	118°17′
Pie Town, NM	34°18′	108°07′
Saint Croix, VI	17°45′	64°35′
Owens Valley Radio Observatory, Big Pine, CA	Two contiguous rectangles, one between latitudes 36°00′ N and 37°00′ N and between longitudes 117°40′ W and 118°30′ W and the second between latitudes 37°00′ N and 38°00′ N and between longitudes 118°00′ W and 118°50′ W.	

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